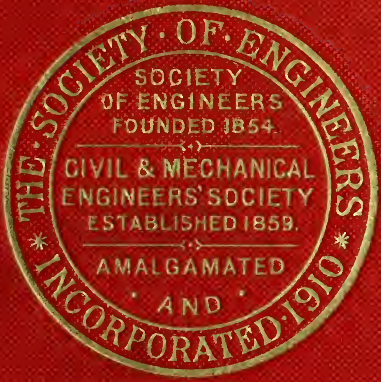
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ALFRED TONY JULES GUERITTE,

President of The Society of Engineers (Incorporated) 1922.

(See page 5.)

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Journal and

TRANSACTIONS FOR 1922.

EDITED BY

ALFRED S. E. ACKERMANN, B.SC.(ENGINEERING).
A.C.G.I., M.Cons.E., A.M.Inst.C.E.,
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ALFRED TONY JULES GUERITTE.

President of the Society for the year 1922.

Alfred Tony Jules Gueritte was born in Blois (France), on March 7, 1875. He was educated at the Government College of that town, and, for the higher mathematical courses, at the Lycée Henri IV., Paris University. Having successfully passed the competitive entrance examination for the École Centrale des Arts et Manufactures, Paris, he obtained his engineering degree at the end of his 3 years' course. About the same time he passed the examination for the brevet of 2nd lieutenant in the Horse Artillery, serving at Orléans, and ultimately reaching the rank of 1st lieutenant. After leaving the army, he joined the group of young engineers whom the late Mr. F. Hennebique gathered round him to establish the theory and practice of ferro-concrete construction. He was soon picked out to take charge of the important department of the Hennebique firm entrusted with the checking of the structural design of all Hennebique works carried out throughout the world outside of France, thus gaining an almost unparalleled experience in that branch of engineering. At the end of 1899, he came to this country to help in the negotiation of important ferro-concrete works in the north of England, and in 1900 established himself in Newcastle-on-Tyne to superintend those early applications of ferro-concrete. In 1903, the late Mr. Mouchel, General Agent for the Hennebique system in the United Kingdom, gave him charge of the North of England and Scotland, and the district soon became a stronghold of ferro-concrete construction. In 1907, he came up to Westminster to become a director of L. G. Mouchel & Partners, Ltd., a position which he still holds. This firm has been responsible for the design of some 4,000 works in Great Britain and the Empire, of such various description as the New General Post Offices, London, Manchester, Glasgow; H.M. Stationery Office, London; Royal Liver Building, Liverpool; Railway Goods Stations, South Lambeth, Birmingham, Bristol, Newcastle; Dock Sheds, East and West India Docks, London, Manchester, Liverpool; Grain

Silos, Manchester Docks, Avonmouth, Dunston; Heapsteads, at Bentley; Scala Theatre, Dublin; Bridges at Longtown, Kilkenny, Waterford, Stakeford; Jetties and Wharves at Tilbury, Dundee, Purfleet, Newport, etc.

Considering it a duty to respond to the call of his country in public matters, and a firm believer in the necessity of the Entente Cordiale, he has been for many years adviser to the French Board of Trade on questions affecting Great Britain and France, and consulting engineer to the French Embassy in London. He was also raised to the presidency of the French Chamber of Commerce in London, and to that of the British Office of the French Ministry of Commerce. A strong supporter of intellectual relations between the two countries, he founded, with the help of our late Member of Council, Mr. Hermann Sloog, the British branch of the Office National des Universités Françaises, the influential Franco-British Inter-University Group, and the British branch of the Société des Ingénieurs Civils de France, of which he relinquished the presidential chair last year.

Monday, February 6th, 1922.

INAUGURAL MEETING FOR THE YEAR 1922.

At the above Inaugural Meeting, the retiring President, the Rt. Hon. Lord Headley, B.A., M.I.C.E., I., inducted Mr. Tony Jules Gueritte, B.Sc.(Paris), M.Soc.Ing.Civ.(France), as President for the year 1922, invested him with the President's Badge of Office, and handed to him the certificate of his election as President.

Mr. Gueritte then proposed a vote of thanks to Lord Headley for his work as President during the past year, which was seconded by Mr. A. Marshall Arter, A.M.I.C.E., F.S.E., and carried by acclamation.

Mr. Gueritte presented the premiums awarded in 1921, as set out at p. 257 of Journal No. 4, 1921.

The **President** then delivered his

PRESIDENTIAL ADDRESS.

Having performed the pleasant task of presenting the premiums, I must now proceed with the more difficult one of delivering the presidential address. At the outset may I say this: in previous years I have heard several times the newly elected Presidents mention that, in their opinion, the Chair would have been more worthily occupied by other colleagues. I think that never such a remark could have greater justification than in my own case. I see here many colleagues who ought to have been in this Chair in my stead. As a Frenchman, I felt strongly during the last two or three years that it would savour of bad taste on my part to accept such a position at the head of an important British Society, when the post could be filled with greater efficiency by a British colleague, and this notwithstanding the keen interest with which I identified myself with the Society's work for years. However, I felt that the honour you were to bestow upon me was meant, in fact, as an honour to French engineering, of which I happen to be, if not a very worthy representative here, at any rate a close-at-hand, a convenient one. It is in this spirit that I felt it my duty to accept, and indeed, to accept with an immensely thankful heart. I saw an opportunity of acting as a link between the two great engineering Communities on both sides of the Channel, of furthering the tightening of the ties between important sections of the educated public in Great Britain and in France, of pursuing the attempt of imparting to each nation a better knowledge of the real character and pursuits of the allied nation. Intercommunication and association has never been more necessary than at present. The scheme of association between British engineering societies, which has been initiated by our own Society has been carried out with such success so far that we are now able to count no fewer than 10 societies associated with us, viz. :—

Battersea Polytechnic Engineering Society,
Birmingham Association of Mechanical Engineers,
University of Birmingham Engineering Society,
Crystal Palace Engineering Society,
Derby Society of Engineers,
Gloucestershire Engineering Society,
The Polytechnic (Regent Street) Engineering Society,
Queen's University (Belfast) Engineering Society,
Stoke-on-Trent Association of Engineers,
Wolverhampton and District Engineering Society,

so that we represent an aggregate membership of nearly 2,500. We hope to give to this movement a still greater impulsion during 1922. And if, as we hope, we are able to abolish frontiers and promote an association of interests between British and French institutions, we shall consider that we have done useful work. Nations ignore each other too much ; tourists and travellers see things too superficially, and it is only when specialists meet frequently their colleagues of other lands that real understanding may be secured.

In this train of thought, it has occurred to me that it would be proper to sketch before you the great lines of *technical education in France*, from its lower to its higher degrees. The French Government and Parliament have always taken great interest in educational problems, and have paid of late a good deal of attention to trade and technical education. New laws have been passed concerning apprenticeship, with a view to allow the largest possible number of children to receive solid professional teaching and, in order to insure the efficiency of this army of able workers, loving their trade and working with taste and pleasure, care was taken to form the necessary leading workers, foremen, shop managers and engineers. The law of July 25th, 1919, organises compulsory technical training for young workers of both sexes under 18 years of age who are unable to go to full-time technical schools. For factory or commerce employees, trade courses have been already organised in 56 out of 89 territorial departments, and the scheme is gradually being extended to the remainder of the territory. The organisation is as elastic as possible, based upon the customs in the trade selected, and adapted as much as possible to local con-

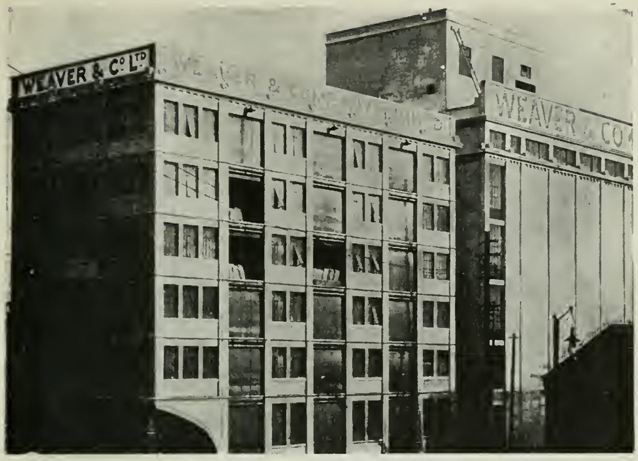


FIG. 1.—WEAVER'S FLOUR MILL AND GRANARY, SWANSEA.

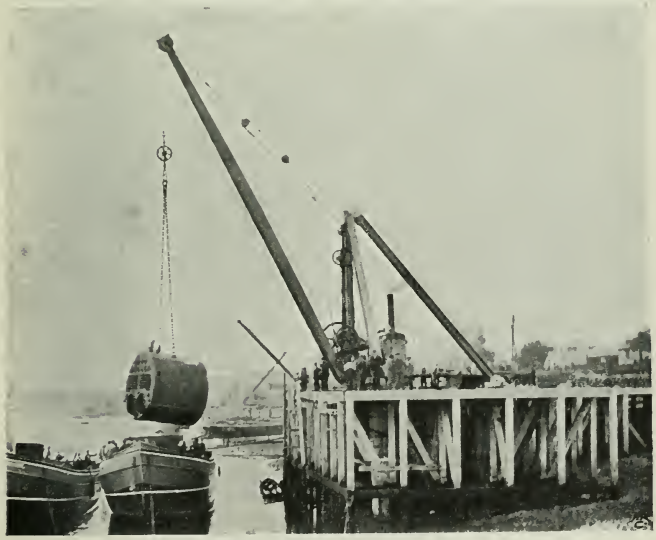


FIG. 2.—WOOLSTON JETTY.

ditions. Where necessary or advisable the needs of small industries, and even of "one-man" trades are taken into account, both as regards industry and commerce, and indeed even as regards agriculture.

Children who, after having received their elementary education, do not become apprentices, may avail themselves of the "*Practical Schools of Commerce and Industry*," the number of which is at present 87 : 46 schools of commerce and industry for boys ; 16 schools of industry for boys ; 5 schools of hotel-keeping for boys, and 20 schools of commerce and industry for girls. The teaching staff of these schools is trained at the so-called "*Normal School of Technical Education*," which was created in 1912. These schools supply well trained workers. of sound trade knowledge, many of whom become foremen, draughtsmen and the like. Statistics show that 75 per cent. of the pupils, when leaving school, take up posts in factories or business houses, and 15 per cent. pursue their studies in technical Schools of higher degree.

Fig. 3.—C.W.S. Warehouse, Newcastle.

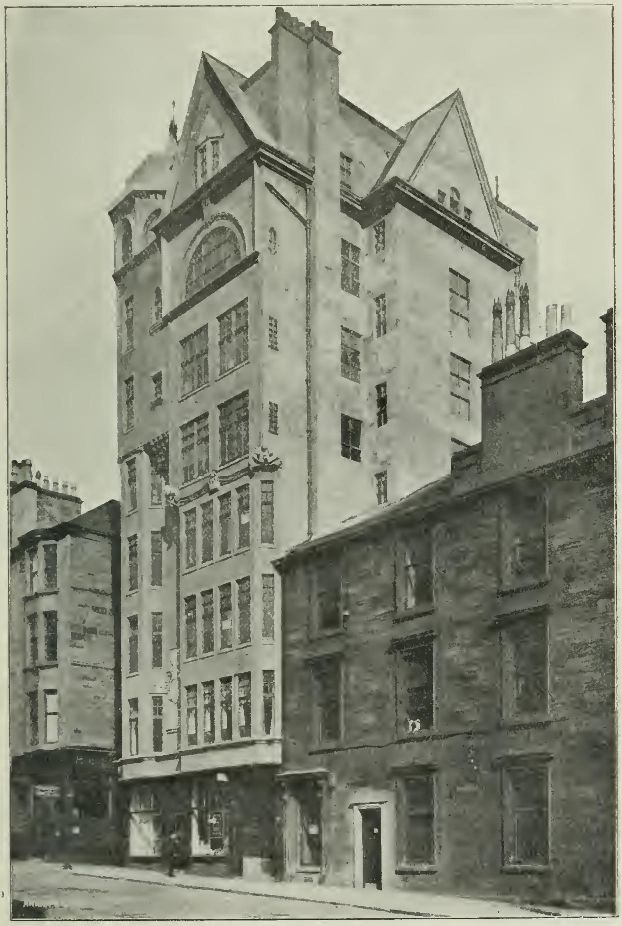


FIG. 4.—LION CHAMBERS, GLASGOW.

Another type of school which is being gradually set up under the guidance of the Under Secretary of State for Technical Education (and may I seize this opportunity to thank the very able Under-Secretary, Mons. Gaston Vidal, for the information with which he was good enough to supply me recently), is the "*Trade School.*" These are smaller and less elaborate, and, therefore, less costly than the previously mentioned ones, but well defined in their character and aim ; they follow closely as regards duration, programme and organisation, the requirements of special trades, and are already helping to renovate and give new strength to interesting local and minor industries. They are, in fact, shop-schools, directed towards a purely practical goal, and under the guidance of the interested trades-people themselves.

Very important and specialised are the *Watchmaking Schools* of Cluses (1848) and Besançon (1862), which enjoy a well deserved reputation.

The City of Paris owns several important trade schools ; 7 are for boys, and enjoy a great reputation : *Boulle*, for furniture ; *Diderot* and *Dorian*, for forming extremely high class artisans, not to say artists, for iron and wood work ; *Etienne*, for printing, binding and generally all the book industry ; *Bernard Palissy* and *Germain Pilon*, form industrial artists in ceramic work ; and the *School of Industrial Physics and Chemistry*, trains for chemical engineering.

Paris possesses also 8 technical schools for girls, dealing with all those branches of industry which concern ladies' requisites, and for which the Paris trade is so justly famous.

At a higher rung of the ladder we find the *National Professional Schools* of Armentières, Epinal, Nantes, Vierzon, and Voiron. They aim, on the one hand, at training foremen, shop-managers, draughtsmen, and on the other, at educating their pupils for the competitive entrance examination of the *National Schools of Arts and Trades.* The training extends over a period of four years ; approximately 350 pupils leave the National Professional Schools every year, 55 per cent. of whom secure positions in factories or works, whereas 38 per cent. pursue their studies further still in the Schools of Arts and Trades. The latter are 6 in number, at Aix, Angers, Châlons-sur-Marne, Cluny, Lille and Paris. They educate shop managers, engineers and directors or administrators mostly for the mechanical industries, who find employment almost throughout the world. A fair number of pupils when leaving at the end of their three years' training seek and secure admission into the *Central School of Arts and Manufactures* of Paris, the highest non-military school of engineering in France, whose engineers have an all-round training and specialise only during their third and last year in one of the four branches: mechanical, constructional, metallurgical and chemical.

It will be seen that a brilliant boy who starts in the Professional School, followed by the School of Arts and Trades, and completes his studies at the Central School, will have had a technical training extending over exactly 10 years.

In addition to the above-mentioned Schools, one should not omit the *Conservatoire National des Arts et Métiers*, in Paris, where the evening tuition is both highly theoretical and practical, and is free. It may be considered as the "University for the People."

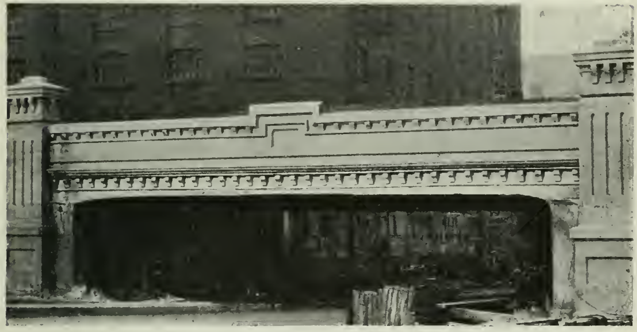


FIG. 5.—BURLINGTON STREET BRIDGE, LIVERPOOL.

The famous *Polytechnique School*, the entrance examination for which is perhaps the stiffest in the world, is under the control of the French War Office and trains officers for the corps of Naval Engineers, Pioneers and Artillery; and also for the civilian services of State bridge and road engineering.

The *National High School of Mining*, in Paris, the *National School of Mining*, in St. Etienne, the *National School of Roads and Bridges*, in Paris, are under the control of the Ministry of Public Works and their engineers are highly qualified too.

By the side of these State or Municipal Schools, we find a number of private schools under Government supervision, as for instance:—

The Higher School of Electricity; *The School of Industrial Electricity and Mechanics*; *The Special School of Public Works*, in Paris; *The School of Engineers*, in Marseilles; *The Chemical Institute*, of Rouen; *The Metallurgical and*

and Mining Institute, of Nancy; *The Northern Industrial Institute*, at Lille; *The French School of Leather Tanning*, at Lyons; *The School of Spinning and Weaving*, at Epinal, etc.

Quite recently have been founded an *Institute of Optics* and an *Institute of Ceramics*, which are full of promise.

It should be mentioned also that in various Universities, Technical Institutes have been created, as for instance at Nancy, Lille, Grenoble, Toulouse, Caen, for electro technics and at Grenoble for paper making and hydraulics.

The subject is too vast to be completely dealt with in the time at my disposal this evening. My aim has been merely to outline it, and perhaps I may be given the opportunity later in the session to complete certain details, especially as regards the higher degree Schools.

In order to comply with the custom which requires the newly elected President to describe in his address recent developments in the branch of engineering to which he belongs, I shall now proceed to sketch out rapidly the progress of ferro-concrete construction in the United Kingdom.

The process is now so widely and generally adopted that it seems unnecessary to describe its principles and methods of application. It seems indeed difficult to realise that 25 years ago it was absolutely unknown in this country. It was in 1892, that the late François Hennebique gave, in France and Belgium, a wonderful start to the idea, thanks to his extraordinary intuition of the possibilities and intrinsic properties of the new material. From the very first his applications were so bold and startling that they have hardly been exceeded in daring up to this date. The introduction of the process into this country was due to the enthusiasm of my late senior partner, L. G. Mouchel, who, in 1897, carried out his first works at Southampton, a river retaining wall founded on ferro-concrete piles, and at Swansea.

British engineering circles were much startled by the boldness of such early works as Weaver's Flour Mill, in Swansea (1897), with its striking cantilevered part, Fig. 1; The Woolston Jetty (1899), founded on ferro-concrete piles, Fig. 2; and the C.W.S. Warehouse, at Newcastle (1900), built without deep foundations as a box on the top of very soft ground and designed so as to sink a few inches while taking its bearings upon it, but without ill effects, Fig. 3. To this day those three early works remain in a perfect state of preservation.

The range of applications widened rapidly, the Mouchel-

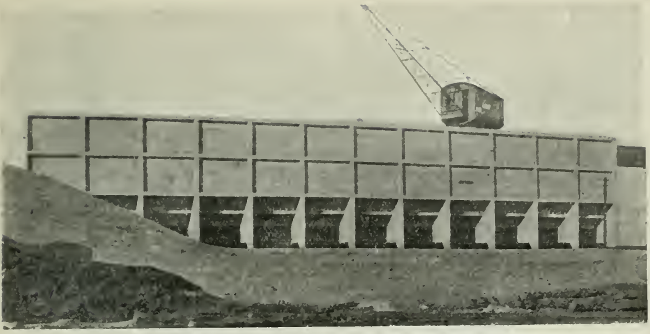


Fig. 6.—Coal Bunkers, Plymouth.

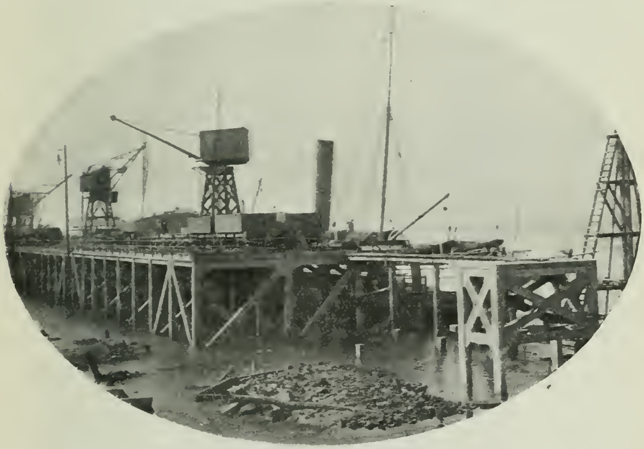


Fig. 7.—Coignet Jetty, Middlesbrough.

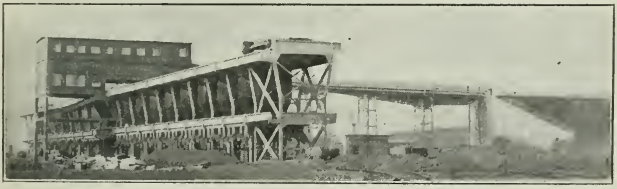


Fig. 8.—Ore Bunkers and Approach, Irthlingborough.

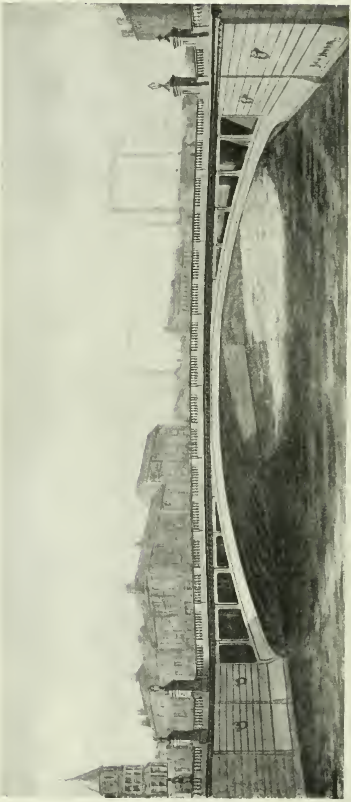


FIG. 9.—WARRINGTON BRIDGE.

Hennebique System remaining the only one in the field until 1906, with such structures as the following to its credit :—

1903—New Bridge Street Goods Warehouse N/C.
1906—Lion Chambers, Glasgow (Office Building), Fig. 4.
1901—C.W.S. Grain Silos, Dunston.
1906—Circular Grain Silos, Dunston.
1903—Burlington Bridge, Liverpool, Fig. 5.
1900—Dagenham Jetty.
1906—Harwich Parkeston Quay.
1904—Ouseburn Culvert.
1900—Bournemouth Water Tower.
1906—Plymouth Coal Bunkers, Fig. 6.

In 1906, the Coignet System, also of French origin, made its appearance in England, with the construction of a big tobacco warehouse, at Bristol. Typical examples of this firm's work are : The New Money Order Department, Holloway (1909) ; a 2,000-ton Ore Bunker for the British Aluminium Co. (1911) ; Wharf at Port Talbot (1913) ; Jetty at Middlesbrough, Fig. 7.

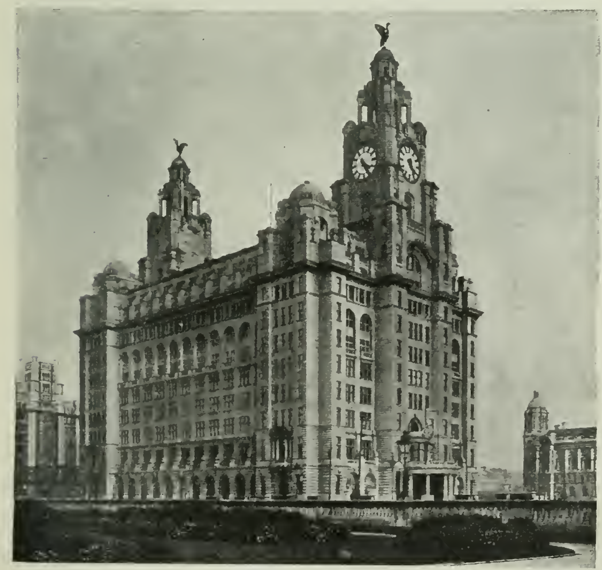


FIG. 10.—ROYAL LIVER BUILDING, LIVERPOOL.

The Indented Bar System, American, made its "début" also in 1906. Typical examples are a warehouse at Manchester, for Ralli Bros.; a coal bunker at Glasshoughton; a viaduct at Irthlingborough, being the approach to an ore bunker, Fig. 8; warren girders in a shed at Royal Albert Docks; a band stand at Weston-super-Mare.

The Helical Hooping System, devised in Paris, by M. Considère, was introduced in this country in 1907, on a wharf at Aberdeen. Other typical works are jetties at Redcar and Gravesend, and bridges at East Ham and Warrington, Fig. 9.

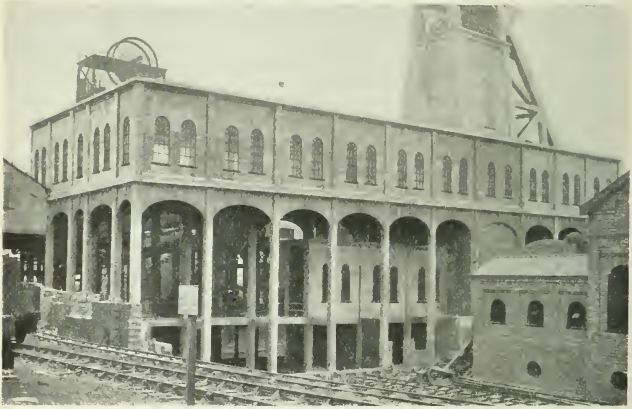


FIG. 11.—BENTLEY COLLIERY HEAD GEAR.

From that time onward, the success of the pioneers attracted many other engineers from foreign lands, and also induced British engineers to give themselves to the study of the new process. The number of reinforced concrete designers has consequently become very great. In fact, it becomes a matter of some difficulty to find people who think they are *not* "experts" in the matter.

As examples of works carried out during the period which followed the 10 first years of ferro-concrete work in this country, I picked out the following typical Mouchel works to give an idea of the diversity or importance of applications of the new material:—

Bridge at Longtown.
The first Skyscraper in Great Britain: the Royal Liver Building. Fig. 10.
The first Pithead gear in Great Britain: Bentley Colliery. Fig. 11.
Chimney Shafts.
Tilbury Atlantic Liner Jetty.
Ore Bunkers, Port Talbot, 21,000 tons.
Steamship "Armistice."

While the work of practical application was proceeding, technical writers began to devote their attention to the subject. Among the first to write must be mentioned our past President, Mr. W. Noble Twelvetrees, and Messrs. Marsh and Dunn; among later comers, Messrs. Cantell, Adams and Faber. The British literature on the subject has become imposing (were it only by its bulk). Among the few books having interesting features, I must mention (in addition to those from the above-mentioned writers), those by Messrs. Ball, Coleman and Andrews. A great number are fairly indifferent; and the reasons for the existence of others remain to me a mystery.

It may, perhaps, not be out of place in this short historical essay, coming as it does on the 25th anniversary of the introduction of ferro-concrete in this country, to mention the names of eminent British engineers or architects who, by their open-mindedness contributed in helping the new industry during its first 10 years. Among those—who, alas! are now departed,—were:—William Bell, of the N.E. Railway; Jacomb Hood and W. R. Galbraith, of the L. & S. W. Railway; W. H. Hunter, of the Manchester Ship Canal Company; A. G. Lister, of the Mersey Dock and Harbour Board; W. W. Squire, of Bristol Docks; John Wilson, of the G.E. Railway.

And among those whom we hope to see long with us are:—Messrs. W. Y. Armstrong, of the G.W. Railway; E. Cooper-Poole. F. F. L. Harris and L. G. Ekins, of the C.W.S.; Frank Latham; C. S. Meik; R. Gordon Nicol; S. Sidney Platt; Sir Henry Tanner; J. Hannay Thompson; L. H. Tressider; to cite just a few.

Mr. J. W. Wilson, M.Inst.C.E., F.S.E. (Past President), proposed a vote of thanks to the President for his address, which was seconded by Mr. C. T. Walrond, F.S.E., A.M.I.C.E., A.M.I.E.E., and carried by acclamation.

AIR-LIFT PUMPS.

By J. A. Coombs.

Read before the Wolverhampton and District Association of Engineers (associated with this Society), on February 27, 1920.

The air-lift pump is extremely simple, and has been known for over 40 years. All that is required is to drop a pipe into a bore hole and force air through it and the water will rise in the bore. A mixture of air and water is lighter than water, hence the water outside the bore will force the lighter mixture upwards. Dr. Poléh, of America, was the first to discover the

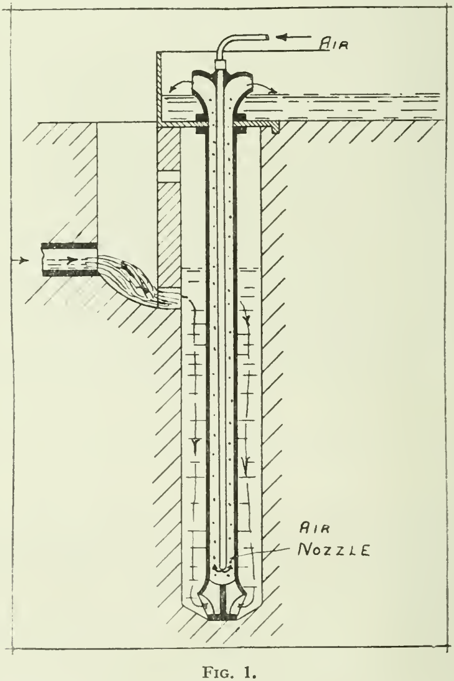


Fig. 1.

A simple form of air-lift pump for lifting water from a shallow well.

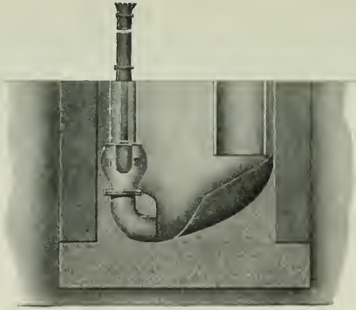
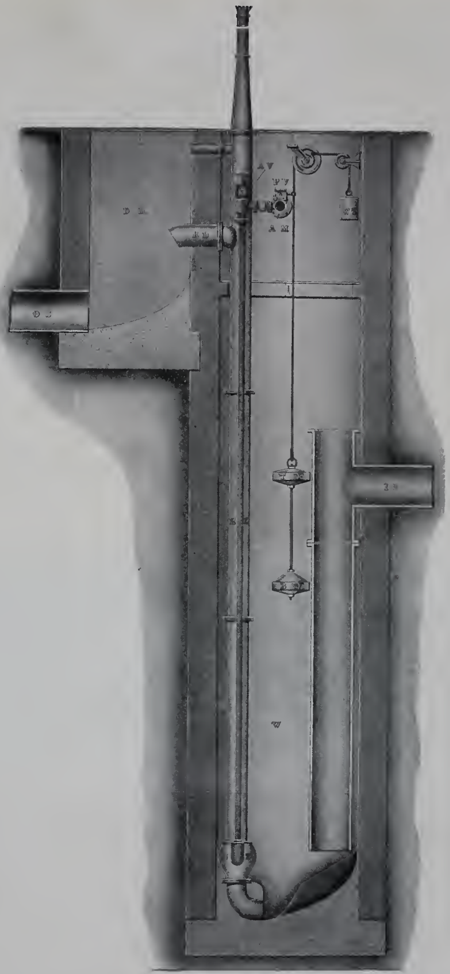


Fig. 2.

An automatic air-lift pump for lifting crude sewage. The air supply is controlled by a valve of the piston type, which in turn is operated by a pilot valve of the " D " type, as used in simple steam engine cylinders. The position of the pilot valve depends upon floats. If sewage flows into the well and rises above the top float, the floats rise and the pilot valve lets air in to one side of the piston valve, which then passes air to the " lift," which begins to operate, and continues to do so until the flow of sewage ceases, or the lift overcomes the flow sufficiently to lower the sewage in the well below the bottom float, which then falls, reversing the pilot valve cutting off the air supply, thus causing the pump to cease work. The air lift remains inoperative until such time as the sewage again rises above top float.



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An automatic air-lift pump for lifting crude sewage. The air supply is controlled by a valve of the piston type, which in turn is operated by a pilot valve of the "D" type, as used in simple steam engine cylinders. The position of the pilot valve depends upon floats. If sewage flows into the well and rises above the top float, the floats rise and the pilot valve lets air in to one side of the piston valve, which then passes air to the "lift," which begins to operate, and continues to do so until the flow of sewage ceases, or the lift overcomes the flow sufficiently to lower the sewage in the well below the bottom float, which then falls, reversing the pilot valve cutting off the air supply, thus causing the pump to cease work. The air lift remains inoperative until such time as the sewage again rises above top float.

principle of the effect described, but due to air-lifts having been used prior to his discovery, master patents were not obtainable, and due to its simplicity many people with insufficient pneumatic and hydraulic knowledge adopted it with poor results; hence the bad name usually attached to the air-lift pump.

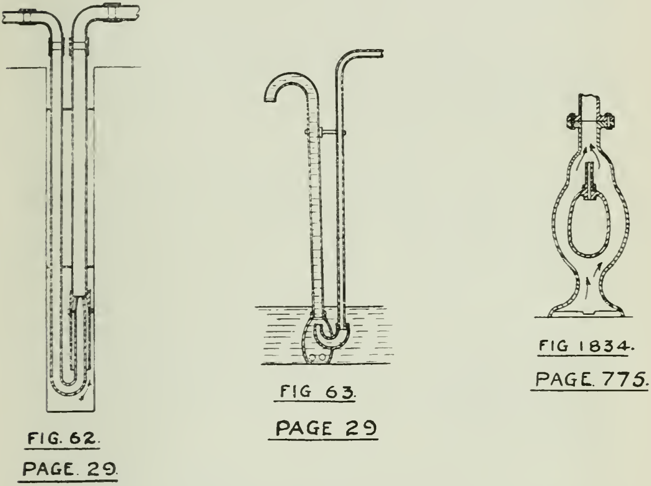


FIG. 62.
PAGE. 29.

FIG 63.
PAGE 29

FIG 1834.
PAGE. 775.

VOL. I. DICTIONARY OF MECHANICS.

PUBLISHED BY CASSELL PETTER & GALPIN.
ABOUT 1875.

FIG. 3.

The above sketches are traced from Vol. I. of the *Dictionary of Mechanics*, published by Messrs. Cassell, Petter, & Galpin, about the year 1875. They are air-lift pumps which were in actual use in the oil wells of Pennsylvania. The explanation of their action, as given in the *Dictionary*, is based on the Giffard ejector principle. Other forms of air-lift pumps are shown, and include both the inside and outside air supply pipe.

It is often assumed that electric transmission is more efficient than pneumatic, but this is not so, especially now that electrical welding of W.I. pipes is possible giving bottle tight joints. The usual loss in case of C.I. pipes with lead yarn and caulked joints is $2\frac{1}{2}\%$ of the initial test pressure per hour. Thus with a velocity of air through the pipes of 20 ft. per second, the leakage losses are a fraction of 1%. The air pressure losses are usually less than 5%.

Mr. W. H. Cunliffe evolved the following formula for air-lift pumps—

$$Vm = K \frac{LG}{S}$$

where Vm = Volume in cu. ft. of air required per minute at the mean pressure between that at the nozzle and that of the atmosphere.

K = constant.
L = lift in feet.
G = gallons of water per minute.
S = submergence of nozzle in feet.

This simple formula was used when the Tunbridge Wells (1891) and other air-lifts were designed.

In *Engineering* of February 12, 1904, Mr. C. C. Mason gave the relation of Vm to Vo as—

$$Vm = \frac{p_o V_o}{p_i - p_o} \log_\epsilon \frac{p_i}{p_o}$$

where p_o and p_i are the absolute pressures in lb. per sq. in. of the atmosphere and the pressure at the nozzle respectively, and Vo = Volume in cubic feet of free air required.

By substituting Mr. Mason's value for Vm in Mr. Cunliffe's formula we obtain—

$$V_o = K \frac{L\,G}{S\left(\frac{p_o}{p_i - p_o} \log_\epsilon \frac{p_i}{p_o}\right)}$$

The constant K has to allow for all losses, including :—

(1) Friction in rising pipe.
(2) Slip of air through the water.
(3) Kinetic energy loss at point of ejection.
(4) Air losses in pipe line and nozzle.

Up to the present these have not been put into a reliable form, though many theories have been published. Prof. Osborn Reynolds, many years ago, showed that when the velocity of water in a tube is more than a certain critical and small amount, eddies are formed throughout the whole of the water in the pipe, and thus energy is lost due to molecular friction as well as that of the water against the pipe, but before the critical velocity is reached the stream lines of the water are straight, and there is very little relative motion between them, and consequently little loss due to intermolecular friction. Thus most of the loss is due to the friction of the eddies against one another and against the surface of the pipe. It is probable that the injection of air among these eddies reduces the molecular friction. At all events, the friction in an air-lift is less than that expected. The slip of a bubble is probably about 9 in. to 1 ft. per sec.

The kinetic energy loss is easily calculated, but until we get the larger friction loss, it is not much good worrying about the smaller slip and kinetic energy loss.

The table gives the values of K obtained from the results given by many air-lifts.

After putting down several air-lifts and collecting all data available from these and other sources, the author found that—

$$V_o = \frac{L\,G}{1{,}100\ p_a}$$

where p_a is the I.H.P. per cubic feet of air compressed adiabatically per minute to the pressure at the nozzle.

DESIGN OF AIR-LIFT PLANT.

Assuming the bore hole has been sunk in accordance with the advice of a geologist and well sinker (the well sinker can generally give a fair idea of volume of water which can be expected from a bore hole), the following information will have to be more exactly ascertained.

(1) The rate at which water can be pumped economically from the bore hole.

(2) The depth to which water level will fall when pumping desired volume.

(3) The daily variations of the fall in level due to continuous pumping and the effect of neighbouring wells, if any.

To ascertain this information, it is necessary to test the bore hole, and a temporary plant must be arranged for the purpose.

Types of Air-Lift.—There are two forms of air-lift, one with the air pipe arranged outside the eduction pipe, and the other with air pipe arranged concentrically inside the same.

The author can see only two possible advantages in the former arrangement ; first, that the wetted surface is reduced and according to the accepted laws of fluid friction with homogeneous liquids this should cause a reduction in friction ; secondly, it is easier to vary the size of the eduction pipe to accommodate the expansion of air and thus keep a more or less constant velocity.

The internal air pipe has, however, several advantages :—

(1) The eduction pipe can be put down, as soon as bore hole is complete, of the maximum diameter to suit the diameter of the bore hole. The adjustment of the area of the eduction

AIR-LIFT PUMP.

DIPS, EFFICIENCIES AND VOLUMES OF AIR REQUIRED FOR VARYING LIFTS WHEN LIFTING 100 GALLONS OF WATER PER MINUTE.

Lift in feet. $=L$ (1)	Dip ratio $=\dfrac{10}{\sqrt{L}}+0\cdot5$ (2)	Actual Dip in feet. $=S$ (3)	Air pressure by gauge in lb. per sq. inch at nozzle (4)	Expected efficiency of air-lift $=\sqrt{L}+40$ (5)	I.H.P. per cubic foot of free air compressed by adiabatic compression $=p_a$ (6)	Value of K $=\dfrac{100}{6\cdot24\ (\sqrt{L}+40)}$ (7)	Cubic feet of free air per minute $=V_o$	
							$V_o = K\dfrac{LG}{S\left\{\dfrac{p_o}{p_i-p_o}\log_e\dfrac{p_i}{p_o}\right\}}$ (8)	$V_o = \dfrac{LG}{1100\,p_a}$ (9)
10	3·66	36·6	15·8	43	·0524	0·3726	14·99	17·82
25	2·5	62·5	27	45	·078	0·3561	25·16	28·77
50	1·9	95	41	47	0·105	0·3410	37·40	43· 3
100	1·5	150	65	50	0·141	0·3205	56·0	64·48
200	1·2	240	104	54	0·186	0·2968	84·5	97·74
300	1·08	324	140	57	0·218	0·2811	105·2	125·00
500	0·94	470	203	62	0·265	0·2584	140·7	171·50

The volumes of air in column (8) are those actually required, whereas the volumes in column (9) are the volumes to be allowed for when ordering air compressor, and are about 20% greater than those in column (8).

pipe both to suit the volume it is decided to lift after the preliminary trial, and also to suit the expansion of air referred to, can be made by altering the central air pipe.

(2) The air pipe is independent of the eduction pipe, which greatly simplifies erection and also enables an examination of the air pipe to be made more readily, as the eduction pipe need not be withdrawn for this purpose.

(3) No bends are required at or near the nozzle, but a straight through nozzle can be adopted which will not be choked through fall of grit or rust which may drop from the pipe due to corrosion caused by the water rising in the air pipe when the lift is not working, or by the settlements of solids when at rest.

(4) It is generally accepted that small bore air-lifts are more efficient than large ones. If this is due to the absence of eddies, as the author believes, then the central air pipe is likely to have the same effect as reduction in bore. If so, then the chief advantage claimed for external air pipe does not exist.

The next point to settle is the depth of the nozzle. Generally, this should be as deep as possible, as the greater the ratio of dip to lift the greater the efficiency of lift itself. The following empirical rule will be found to agree with practice :—

$$\frac{S}{L} = R = \frac{10}{\sqrt{L}} + 0\cdot5\text{ ; and } S = 10\sqrt{L} + \frac{L}{2}$$

where R=ratio of dip to lift, S=submergence, and L=lift in feet. The rule gives a ratio of about 1 to 1 for 300 feet lift and 2½ to 1 for lifts of 25 feet. Readers can verify the ratio for 300 feet, but the author does not know of any published figures for lifts of 25 feet. He therefore gives two examples from his own experience.

As a rule in shallow lifts, it is proportionately more costly to obtain large ratios than in deep lifts; hence probably the adoption of a ratio which might be still further increased with advantage.

Efficiency of lift : Isothermal expansion.	Index letter.	Equivalent diameter after deducting area of air pipes.	Lift in feet.	Dip, and Lift Ratio.	Gallons per hour.	Cu. ft. of free air per minute.
45·4	A	11″	21·25	51·6 2·42 : 1	1,200	300
35·09	B	16¾″	28·75	48·0 1·67 : 1	10,000	2,850

Lift A.—The air was measured by orifices on the suction side of the air compressor, and the water by direct measurement into a reservoir of large area.

Lift B.—The air was measured by piston displacement, but as the air valves were mechanically operated, and had a known efficiency which has been allowed for, any volume given is fairly accurate.

The sewage lifted was measured by a notched weir in the inlet sewer. The eduction pipes in both cases were parallel, and the air pipe was arranged inside the same. The efficiency given is ratio of the potential H.P. of water raised (assuming it to be allowed to flow back to source), to the H.P. of the air expanded isothermally to atmospheric pressure.

Eduction Pipe.—The author is in favour of parallel eduction pipes, as the advantage of taper is only a possible reduction in friction, whereas there is a considerable increase in the volume of air required, due to taper, if Mr. Cunliffe's displacement theory is accepted. It is, however, advantageous to flare out the top of the eduction pipe in order to reduce the kinetic energy losses in the discharged water. The taper should follow a parabolic curve, and the discharge mouth may be 4 times the diameter of the bore.

The diameter of the eduction pipe should be made rather large (if the bore hole allows), so that the velocity of air and water at the nozzle does not exceed 10 feet per second.

Diameter of Air Pipe.—The larger the air pipe the better. For a preliminary trial, an air velocity of from 30 to 40 feet per second can be allowed so as to leave the largest effective area in the eduction pipe, and also to reduce the cost of the air pipes to a minimum. The loss in friction can be calculated by well-known rules. For the permanent air pipe, the diameter will be calculated so as to keep the velocity in the eduction pipe within economical limits, say within 10 to 30 feet per second, bearing in mind the effect of air friction. The air pipe should have internal couplings, the entrance and exit of couplings for air being bevelled to reduce friction. Both air pipe and eduction pipe should be made of galvanized mild steel with long screwed couplings. In great depths the upper lengths can be made of extra thickness to support the weight of the pipes below.

Air Nozzle.—Though fine bubbles no doubt increase the efficiency, the small holes necessary are liable to choke; thus it is usual to make the ports of large area. The sketch below gives the type of nozzle the author uses.

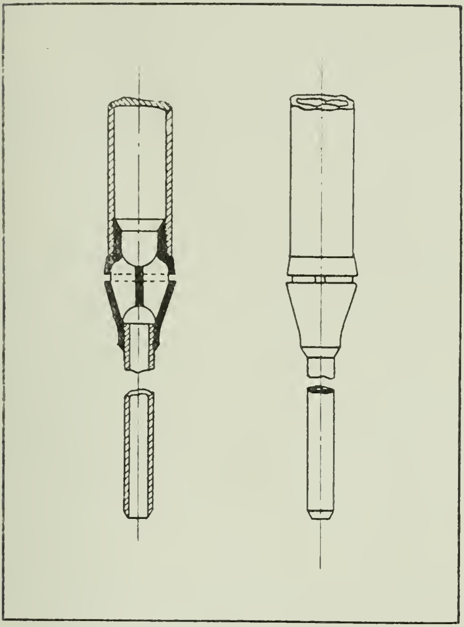


FIG. 4.
The nozzle adopted by the author.

A tripod gantrey should be fixed over the well permanently, for the purpose of withdrawing the air and eduction pipes periodically for examination. Suitable tackle for screwing up joints should also be supplied.

The air main from the air receiver to the well should be designed so that the friction does not exceed 5% of air pressure. All stop valves on air mains should be of the sluice valve or straight through type.

Air Compressor.—A horizontal, but preferably a vertical, fully enclosed single cylinder, double acting compressor will probably be adopted for air pressures under 100 lb. per sq. inch, as the gain by an extra stage at this pressure is only 10%, or about equal to the extra friction caused by a second cylinder ;

and a tandem, or side by side double stage air compressor for pressures between 100 and 300 lb. per sq. inch. In either case a belt driven or geared compressor will be chosen so as to give easy adjustment of speed from time to time to suit output.

In many cases the water from the bore holes can be used for water jackets and also for fore and intermediate coolers. The coolers should be of the tube condenser type with large water connections to take, where used, the whole of the water delivered by the air-lift.

Lubrication.—Mechanically operated lubricators should be used for all wearing surfaces.

Capacity of Air Compressor.—It can be shown that the efficiency of air compressors varies only slightly between full and half speed; thus a compressor well above (say 20%) its duty can be chosen, bearing in mind the extra duty of air lifts to suit emergency calls. It is also advisable to obtain the permanent air compressor for the preliminary trials, as this forestalls any controversy on this point, and this may occur due to difference in mechanical efficiency of the permanent and temporary plants. It also ensures a known efficiency, straight from the makers, as a check on air measurements, and this is more important in preliminary tests than in permanent running.

Undoubtedly a deep well pump would show an overall efficiency of 50% in excess of these figures, but this only affects power cost, which after all is only a factor of the running charges.

Cost of Attendance.—Interest on capital expended, repairs, and depreciation are together an equally important factor, and if these and the following conditions are taken fully into account, then the air-lift pump will be chosen in many cases.

In case of an air-lift pump the efficiency is fairly constant, whereas in deep well pumps the efficiency begins to fall off at once and fairly rapidly where gritty water has to be lifted. Thus it is the average efficiency from the time of starting to time of renewal of valves which should be taken into account. Allowance must also be made for the stoppage of a deep well pump from time to time.

The extra comfort of having a plant in which all the working parts are under direct supervision in the engine room, so that the attendant can tell instantly by sound if all is right, and locate any trouble at once by inspection, is an important factor.

A much greater volume of water can be obtained by an air-lift from a given size bore hole, and not only does this affect prime cost and other overhead charges, but in case of an increase in demand it becomes an important factor.

With deep well pumps the prime mover must adjoin the pumps, whereas the air-lifts may be ½ mile, if necessary, from air compressor, and in some cases this will enable a reduction in attendance, as the compressor can be placed in the main engine room.

Another important factor in favour of the air-lift compared with deep well pumps, is that as drop of water level is proportional to the volume pumped, and that several air-lifts can be operated from the same central air compressor, thus the drop due to using several air-lifts is reduced. Thus it is quite legitimate to take these factors into account when comparing the overall efficiencies of air-lifts and deep well pumps. It must also be borne in mind when this point is considered that small air-lifts are more efficient than large ones.

Only those who have had charge of both deep well pumps and air-lifts lifting gritty water appreciate the comfort of the latter, and know why they (in spite of the greater power required) are so largely used in the United States of America, and are now becoming more popular in this country.

A reason why engineers do not often specify air-lifts is that little or no reliable data or simple formulæ for designing air-lifts has been published. Thus the engineer by specifying air-lifts places himself and his clients at the mercy of the contractors. If the contract follows the lowest tender, the contractor is likely to be equally ignorant of the best design to suit the local conditions, and the plant from an efficiency point of view will be a failure.

The author might add in reference to the settling out of the sand from water, that settlement tanks, as designed by Mr. Wm. Clifford, A.M.I.C.E., of Wolverhampton sewage works, in connection with sewage sedimentation, are simple and would prove effective for this purpose.

March 6th, 1922.

T. J. GUERITTE, B.Sc.(Paris), M.Soc.Ing. Civ.(France), F.S.E.,
PRESIDENT, IN THE CHAIR.

THE TESTING OF SMALL ELECTRICAL PLANT. (First Part.)

By DR. C. V. DRYSDALE, O.B.E., D.Sc., F.R.S.E., M.I.E.E.

The importance of the accurate testing of devices for electrical power supply or conversion should need little emphasis, but it hardly seems of late to have received the attention it deserves, and it is to be feared that few manufacturers have concerned themselves greatly with the testing side of their work. So long as consumers are content merely to obtain machines which will fulfill their purpose at the lowest initial cost without troubling much about efficiency, this may seem the most economical policy, but it does not conduce to a healthy state of the industry or give encouragement to the improvement of designs. Sooner or later the prestige of our manufacturers will depend upon the efficiency of their products, and a healthy rivalry in securing the most economical designs should be encouraged. Accurate testing is not only of value in establishing confidence, but it is of the greatest importance to the designer in enabling him to check the correctness of his calculations and guiding him to further improvement.

One great obstacle to the establishment of complete testing arrangements in factories is the high cost of the apparatus and the time required in testing, which is a handicap on cheap production. It appears, however, that this is largely due to the fact that insufficient attention has been given to the standardisation of testing methods and apparatus so as to obtain the best results with the minimum of expenditure and time. The number of testing methods which have been devised is legion, but little consideration has been given to their respective merits. Again the range to be covered in testing is so large that if ordinary instruments are employed it requires a most formidable equipment to cope with it, and if these instruments are merely coupled up as required they are liable to be damaged or burnt out, and little reliance can be placed on their indications. Lastly, we have to deal with machines for four different kinds of supply, direct current, single phase, two phase, and three phase, and this, combined with the variations of power, voltage, and frequency makes the problem appear extremely complicated.

It is therefore proposed in the present paper to discuss the question of testing methods and instruments, with the view of coming to some conclusion as to the best devices and their assembly, in order to enable testing to be carried out systematically with the maximum of accuracy and convenience, and the minimum of initial and working cost.

This subject especially engaged the author's attention in the development of the electrical engineering laboratories of the Northampton Institute, and although considerable time has elapsed, there does not seem to be any reason for greatly modifying the conclusions derived from this experience. As the machines dealt with in the laboratory rarely had an output exceeding 10 or 15 H.P. this paper is especially concerned with the testing of such small machines, but some of the methods and devices appear equally applicable to machines of larger power.

The chief quantities to be determined in the testing of such plant are as follows :—

(*a*) The electrical or mechanical power input or output.
(*b*) The electrical or mechanical power losses.
(*c*) The regulation-variation of P.D. or speed, etc.

We will first consider the measuring instruments or devices, next the testing method and arrangement of the devices, and finally the actual testing with examples.

I.—Instruments.

A complete discussion of testing instruments would need a treatise in itself, and it is proposed here to deal only with those which are most suitable for plant testing purposes and a few suggestions for further improvement. As this paper only professes to deal with small machines, instruments for very heavy currents or high voltages will not be considered.

The essential instruments for plant testing are as follows :—

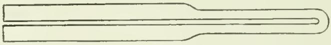
Electrical : Ammeters, Voltmeters, Wattmeters, and Frequency Meters.
Mechanical : Tachometers, and Brakes or Transmission Dynamometers.

Ammeters.—Unless entirely separate arrangements are made for direct current and alternating testing, good soft iron ammeters are on the whole the most suitable. There is no difficulty in producing instruments of this type which are accurate well within 1 per cent. at all working frequencies, and if fixed and calibrated *in situ* considerably higher accuracy can be obtained. They have a higher range than most A.C. instruments (sometimes ten-fold) a low power consumption, and are relatively cheap. Instruments of the Nalder or Weston repulsion type with small moving iron, and former wound coils without metal bobbin, have been found most satisfactory.

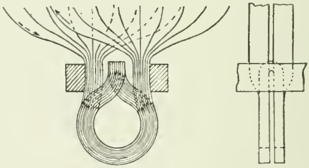
The question of range is of paramount importance in a testing installation not only for reducing the number of instruments, but for avoiding constant changes of instruments with the loss of time and risk of injury involved. In the case of direct current moving coil instruments different shunts may be used, but shunts or transformers are not to be recommended with A.C. instruments.

On this account the writer has given attention to the possibility of extending the range of soft iron ammeters, and has already succeeded in obtaining an instrument having a 150-fold range and of fairly simple construction. This has been done by increasing the range of the ordinary repulsion instrument by adding a separate attraction iron, thus obtaining a 15-fold range, and constructing the coil of ten similar copper strips having approximately equal magnetic effect and connecting them in different series parallel combinations by means of a commutator.

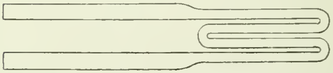
The essential features of this instrument as made for a range from 1 to 150 amperes are shown in Fig. 1. The coil is built up of ten insulated copper strips of the form shown at the bottom. These ten strips are formed together into a two turn circular coil, but with an inflection between the turns, so that the outer strip in one turn becomes the inner in the other turn and so on, each of the ten circuits having approximately equal area and magnetic effect on the movement. This arrangement has the additional advantage of bringing up the ends of the strips in the right order for direct connection to the series-



Form of Strip for 2-20 Turn Coil



Two Turn Coil suitable for Soft Iron Ammeter

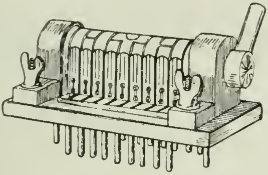


Form of Strip for 4-40 Turn Coil

Fig. 1.

parallel commutator. The strips are clamped together at the top and the whole coil is sufficiently rigid to enable a bobbin to be dispensed with.

The form of commutator hitherto used with this device is of the barrel form employed in the author's wattmeters. Fig. 2, shows the construction of this commutator. Two of the strips are connected to the main bearings through which the current passes to the commutator and the remaining 18 ends are connected to two rows each of nine brushes pressing on the two sides of the commutator. There are four working positions of the commutator giving the combinations (*a*) 10 series, (*b*) 5 series, 2 parallel, (*c*) 2 series, 5 parallel, and (*d*) 10 parallel, the corresponding current ranges being 1, 2, 5, and 10. The commutator and terminals are mounted on the top of the instrument case, and provision can be made for a sliding figure plate to be moved by turning the commutator, and piercing holes in the dial, so that the correct figures for each range are exposed for each range, and the instrument is always direct reading.



SERIES-PARALLEL COMMUTATOR FOR 250 AMPERES

FIG. 2.

The movement is of the ordinary Nalder type with spring control, but having in addition to the fixed internal repulsion iron, an external attraction iron which comes into operation at the higher currents and extends the range. Fig. 3, shows the form of the scale for the all series connections and shows that a good and nearly even scale from 1 to 15 amperes is obtained with this combination, the corresponding ranges for the other combinations being 2–30 amperes, 5–75 amperes, and 10–150 amperes. The change of range can be effected by rotating the commutator without even breaking the circuit, although it may be desirable to do so in order to avoid possible arcing at the contacts.

To make the instrument equally suitable for C.C. and A.C. working the important point is to reduce hysteresis errors to a minimum. This is effected by making the shaft of the moving system of hard steel, which becomes magnetised by the current,

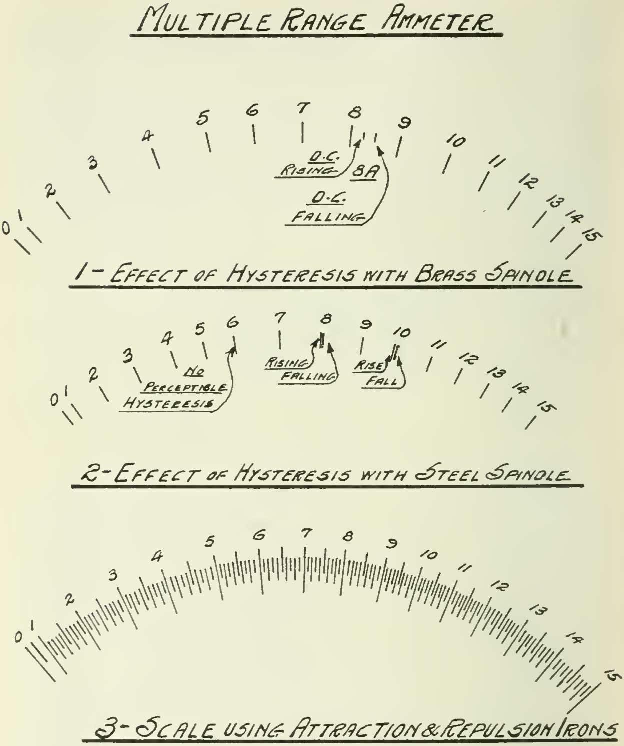


FIG. 3.

and tends to demagnetise the moving iron when the current is diminished. The scale shows the hysteresis error at two or three readings, the lower mark being when the current is raised from zero, and the upper mark when it is diminished from the maximum value, the difference being only about 0·5 per cent. of the maximum current. This type of instrument has not yet been put on the market, but its advantages for all testing work appear so great that arrangements are now being made for its manufacture. Attempts are also being made to simplify it further by replacing the barrel commutator by the simple form shown diagrammatically in Fig. 4. In this case the ends of the coil strips are brought up between two bus bars connected to the terminals, and are either allowed to spring together or be forced against the bars by an ebonite cam roller effecting the combinations. When all the strips are in contact with one another, we have the all-series combination, but when they are all separated and pressed against the bars the all-parallel combination is secured, while the intermediate combinations are easily attained. This arrangement is far more simple and cheap than the barrel commutator, but its success depends on the possibility of forming the ends of the strips into suitable contacts. If this is done satisfactorily a remarkably cheap and efficient long range ammeter for either direct or alternating current testing will be available.

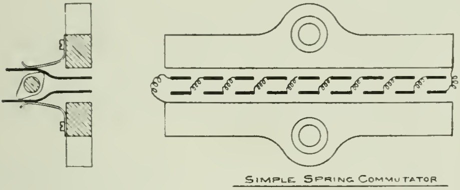
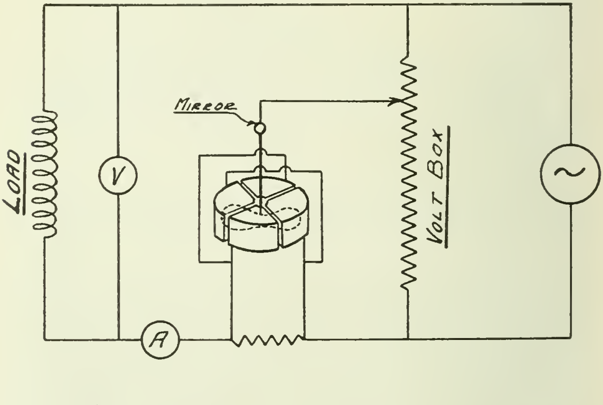


FIG. 4.

Voltmeters.—For purely D.C. testing the permanent magnet moving coil type of voltmeter is certainly the most suitable, but for combined D.C. and A.C. work the Weston dynamometer voltmeter is probably the most suitable type on account of its accuracy and long range.

All electromagnetic voltmeters are of course subject to frequency variation, but this is fairly small and definite in the Weston dynamometer voltmeter. For example a two range instrument of this type for 15 and 30 volts has a frequency error of only 0·4 per cent. at 50 periods, or 1·63 per cent. at 100 periods, while with the 30 volt range this error is reduced 1/4 and it becomes negligible at higher ranges. If a non-inductive series multiplier is used the temperature variation is very small and although the instrument is non-astatic it is fairly thoroughly shielded, so that if care is taken to avoid the proximity of heavy current leads an accuracy of 1/4 per cent. can be relied on. Such an instrument with series multipliers will serve very well for voltages up to 600, while for higher ranges electrostatic voltmeters of the Ayrton-Mather type are very suitable.

Wattmeters.—These are the most important instruments from the point of view of electrical testing as they actually read the power absorbed or generated;—the current and P.D. readings being as a rule merely auxiliary for the purpose of maintaining the proper working conditions and determining the power factor in A.C. testing. A suitable wattmeter for plant testing should have as great a range as possible, be free from inductive or eddy current errors, and should be preferably of the double type which can be used either for single or even two phase or three phase work. There are two main types of testing wattmeters, the electrostatic and the dynamometer forms. The former type which has been chiefly developed by Mr. G. L. Addenbroke, is excellent in principle as there is no question of inductive errors, but it is essentially a reflecting form of instrument. It has given extremely satisfactory results when so installed but requires a considerable amount of care in setting up and calibration. Fig. 5 shows the ordinary connections of an electrostatic wattmeter, and different ranges can easily be secured by using different resistances or shunts across the quadrants. For the majority of purposes, however, the dynamometer form of wattmeter is preferable as it is more robust and portable and can be more conveniently made in the double form for polyphase testing.



ELECTROSTATIC WATTMETER

FIG. 5.

The first attempt at making accurate long range instruments was the type made by the author in 1901,* in which the main coils were made of 10 independent circuits carefully stranded and brought out to mercury cups on the base, whereby the circuits could be combined in various series-parallel combinations. This type of instrument was used for motor and transformer testing and was found so satisfactory that in the following year a double form was devised in which two smaller systems were mounted vertically above each other with their axes at right angles, and this type of instrument has been constructed by Messrs. Tinsley, and improvements have been introduced such as making each of the systems astatic and effecting the changes by barrel commutators similar to those described above. As the working current on each instrument is only 0·02 of an ampere, and the inductance of the moving coil is only about 1·7 millihenries, the inductive error is practically negligible at all working voltages, as the phase displacement at 50 periods and 100 volts supply is only one thousandth of a radian or 0·06 of a degree.†

Resistance boxes of negligible inductance and capacity are constructed which will enable the same instrument to be used on circuits from 50 or 100 volts to 2,000 volts or higher per phase.

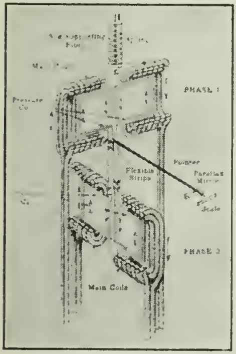


Fig. 6.

An instrument of the torsional form with a large divided head at the top having 500 divisions each of about one millimeter, has readings which can easily be estimated to 1/5th of a division and one per cent. accuracy can be obtained for a 25 fold range for one setting of the commutator, and this can be increased 10 fold by a series parallel combination, so that this degree of accuracy can be obtained for 250 fold range. Fig. 6, shows a recent form of double wattmeter of this type for a maximum current of 100 amperes in each circuit and satisfactory wattmeters of this type have been made for 250 amperes per phase or even higher. The Weston Instrument Co. have also produced shielded dynamometer wattmeters of the deflectional type which are extremely accurate and satisfactory.

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* *Electrician*, March 15, 1901.

† "The Double Dynamometer Wattmeter," *Electrician* Jan. 14, 21, and 28, 1916.

They have also adopted a commutator for putting the two main coils in series or parallel, thus doubling the range ; and have made double wattmeters on the same lines. Tests which have been made on these instruments at the National Physical Laboratory, have shown remarkable accuracy for a portable deflectional instrument, the inductive errors being practically unreadable, so that although they have not the range of large torional instruments above described they are of the greatest possible value where portable instruments are necessary.

Frequency Meters.—The best type of frequency meter for tests at ordinary commercial frequencies is undoubtedly a good form of resonant reed instrument. When well made these instruments will indicate the frequency to an accuracy of one or two tenths per cent. and they are remarkably free from temperature or other variations and take very little power. The only objection to this type is that each reed has, of course, to be calibrated separately and it is of importance that the damping of the reeds should be of the right value to enable the intermediate frequencies to be correctly estimated, but instruments of the Hartmann Kemf or of the Frahm type have been found to be extremely satisfactory in both respects. Instruments with steps of ½ a period from about 30 to 75 periods can be obtained and by polarising the reeds either by an auxiliary direct current or by a magnet this range can be doubled.

There are also various forms of deflectional frequency meters which are now fairly satisfactory, although they are nearly all liable to more or less variation with the wave form of the supply. A form of frequency meter which has just been devised by Dr. Clinker appears to be free from this objection, although the author has had no experience of it. The principle of the instrument is extremely pretty and depends on obtaining resonance with inner circuits composed of a condenser and inductance in series, by varying the latter. This principle is of course well known but Dr. Clinker has applied it to deflectional instruments by arranging the inductance in the form of a moving coil travelling over a tapered electromagnet excited from the supply. This coil is mounted on the spindle of the instrument and is provided with two light connections to which a condenser is attached. The alternating flux in the magnet induces an E.M.F. in the moving coil and consequently a current in the coil or condenser circuit which is generally out of phase with the E.M.F. When the circuit is in resonance with the supply the current in the moving coil is at a maximum but is in phase with the E.M.F. and consequently in quadrature with the flux, so that there is no mechanical force on the coil. As the coil moves over the core its self-induction varies, so that if entirely uncontrolled it automatically takes up the position in which the inductance produces resonance with the supply and the torque is zero. By altering the form of the poles either a close or open scale of frequency can be obtained, and the principle of the instrument appears to be extremely sound, as harmonics, unless of considerable magnitude, should have no effect on it and the instrument should be entirely free from temperature variation.

Wave Form Determination.—All A.C. machines should, as far as possible, be tested on sinusoidal supply, so that wave form determinations should rarely be needed. Should they be necessary, the author has found that for the bulk of cases the Hospitalier Ondograph is by far the most convenient instrument, as it gives an ink trace of the wave form with remarkably little trouble in preparation. This instrument works on the point to point method, a drum being rotated by a synchronous motor from the mains, while a contact maker working with a definite percentage slip, causes successive charges of a condenser and discharges through a moving coil galvanometer actuating the recording pen. The instrument is extremely robust and portable, and although it cannot pretend to the accuracy of a good oscillograph, it gives results which are sufficiently reliable for most engineering purposes.

The A.C. Potentiometer.—Where magnetic flux determinations are required in testing A.C. machines this instrument will be found valuable, and it is also probably the best instrument to employ for all electrical measurements in the case of large machines where the employment of accurate measuring instruments would be difficult owing to large currents and insulation difficulties. This instrument, which was devised by the author in 1909, has come into fairly general use. The principle consists of balancing any P.D. to be tested by a P.D. derived from the potentiometer, the magnitude and phase of which can be varied by the dials and slide wire of the potentiometer and by means of a phase shifting transformer, which varies the phase of the current through the dials. When balance is secured (by means of a vibration galvanometer), the magnitude and phase of the P.D. tested can be read directly on the dials and phase shifter, so that by the use of non-inductive low-resistance standards and volt boxes the P.D. and current and their phase relations can be determined for any machine and its complete vetor diagram obtained.

In the case of magnetic field determinations, a search coil can be inserted wherever desired, and by measuring the E.M.F. in the coil on the A.C. potentiometer, the magnitude and phase of the field can be at once determined. Fig. 7 shows the standard form of D.C., A.C. potentiometer as manufactured by MM. Tinsley & Co.

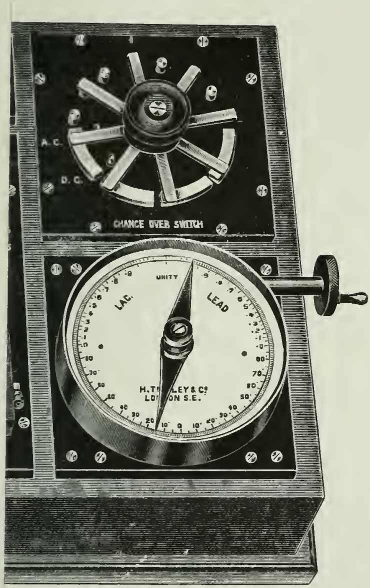
II.—Devices for Mechanical Testing.

It is somewhat curious that although need for accurate mechanical testing has existed far longer than that for electrical measurements, and that mechanical phenomena are comparatively more simple, it is much more difficult even at the present day to make satisfactory tests of the mechanical performance of a machine than of its electrical performance. This was strongly brought home to the author on attempting to produce satisfactory devices for testing electrical machinery. Even at the present day we have no instruments for mechanical testing which are comparable in convenience and accuracy with the ammeters, voltmeters, and wattmeters used in electrical testing.

The two great factors which are required for the testing of rotating machinery are the torque and speed, or their product giving the power, which are respectively comparable to the P.D., current, and power in an electrical circuit. As regards the speed there are of course numerous tachometers on the market several of which are fairly convenient and accurate, but they are all more or less subject to derangement with time, or to temperature and other errors. There are also large numbers of brakes or absorption dynamometers for determining the torque but very few of them are susceptible of high accuracy, or are convenient to use, as the absorption of power requires cooling arrangements which are usually troublesome and frequently lead to difficulties as regards variation of friction. As yet we have no convenient device for mechanical testing which is the analogue of the electrical wattmeter, although there should be no great difficulty in producing a fairly satisfactory device of this kind, and some attempt will be made below to show how this can be done.

Tachometers.—Of ordinary tachometers the centrifugal type, such as the Young speed indicator, is fairly satisfactory, at any rate when fairly new, and its principle is too well known to need description. After considerable use, however, it has been found that most centrifugal tachometers begin to develop looseness in their parts and to become somewhat unreliable, they also take a moderate amount of power to drive them which although of small importance in machines of moderate output may be undesirable in testing very small machines.

Of the purely mechanical instruments perhaps the most reliable is the vibrating reed instrument already mentioned, under the heading of frequency meters. These instruments may be used for speed measurements either by actuating them electrically or mechanically. In many cases the vibration produced by the rotation of the machine is sufficient to actuate


A. C.
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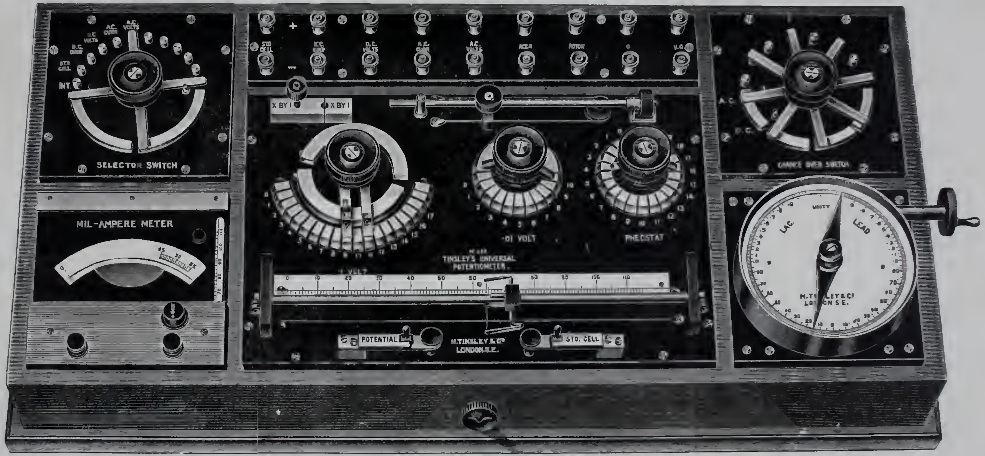
SELECTOR SWITCH
INT.
STD CELL
D.C. CURR
D.C. VOLTS
A.C. CURR
A.C. VOLTS
MIL-AMPERE METER
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ROTOR
V.G
X BY 1
X BY 1
1 VOLT
·01 VOLT
RHEOSTAT
TINSLEY'S UNIVERSAL POTENTIOMETER.
POTENTIAL
STD. CELL
M. TINSLEY & Co
LONDON, S.E.
A.C.
D.C.
CHANGE OVER SWITCH
LAG.
UNITY
LEAD
M. TINSLEY & Co
LONDON S.E.

Fig. 7.

the reeds if the instrument is merely fixed on the motor case or its support, or a cord is taken from some part of the machine to the bar holding the reeds, provision for which is made in the Frahms type of instrument. When used electrically the instrument is connected in series with a battery to a tapping contact on the shaft which makes contact once or more in each revolution and gives the required magnetic impulse to the reeds. This device is frequently very suitable as the same instrument can be used as a frequency meter and tachometer, and in the case of synchronous motors the slip can be readily shown with moderate accuracy by the difference between the frequencies of the reeds when the instrument is excited successively from the mains and from the shaft-contact for the accurate determination of speed and especially of the slip of motors.

The author has found it preferable to use the stroboscopic device which has proved extremely satisfactory. The principle of the stroboscope has long been known and consists of illuminating a regular and geometric figure on the shaft of the rotating machine by a series of regular flashes of known frequency. The most satisfactory method of producing these flashes is to employ an electrically maintained tuning fork, care being taken to employ contacts for maintaining the fork which do not affect its rate of vibration. If this fork is provided with aluminium shutters on its prongs with slits through which the diagram can be viewed, then if the machine makes one complete revolution between one flash and the next the figure will appear to remain stationary. With a fork of frequency 50 periods per second giving two flashes per period, this means 6,000 flashes per minute, and if the machine is running at 6,000 revs. per min., it will appear to be stationary. If the speed is above this value, the machine will gain on the flashes and appear to revolve slowly forward, but if it is below it a backward rotation will be seen, the true speed being given by adding the apparent revs. per min. to 6,000 or subtracting it if it appears to run backward. It is quite easy to detect a change of much less than 1 rev. per min., so that the method is accurate to within 1 in 10,000 if the frequency of the fork is accurately known. If we mount a polygonal figure of r sides on the shaft, it is evident that the machine will appear stationary when the speed is $6{,}000/r$ or twice or three times this value, since we cannot distinguish between one side of the figure and another. Furthermore, if the speed is $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$, etc. times $6{,}000/r$, two stationary polygons will be seen over each other with their angles half way between each other and this is easily recognised. Similarly, if the speed is $\frac{1}{3}$, $\frac{2}{3}$, $1\frac{1}{3}$, $1\frac{2}{3}$, $2\frac{1}{3}$, $2\frac{2}{3}$, etc. of $6{,}000/r$ a triple stationary polygon will be seen. The author therefore designed a standard stroboscopic disc shown in Fig. 8, which enables a large series of

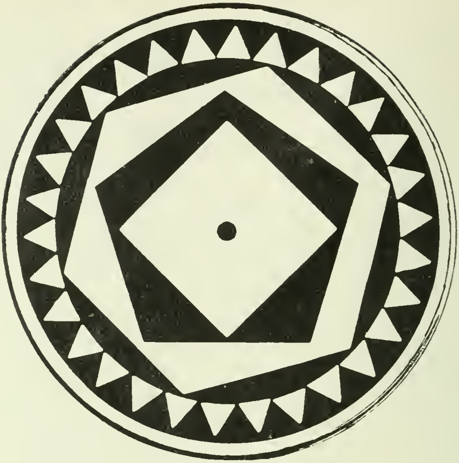


FIG. 8.

speeds to be recognised at a glance. These discs can be obtained in cardboard or enamelled iron, and can readily be attached to the shaft of any machine. In the centre of the disc is a white square, surrounded by a black pentagon, and a white hexagon, while a 30 point rose or star is painted round the periphery. Hence we have with a 50-period fork :—

Single Square, 1,500, 3,000, 4,500, 6,000, 7,500, etc. revs. per min.

Double Square, 750, 2,250, 3,750, 5,250, 6,750, etc. revs. per min.

Triple Square, 500, 1,000, 2,000, 2,500, 3,500, 4,000, 5,000, 5,500, etc. revs. per min.

Single Pentagon, 1,200, 2,400, 3,600, 4,800, 6,000, 7,200, etc. revs. per min.

Double Pentagon, 600, 1,800, 3,000, 4,200, 5,400, 6,600, etc. revs. per min.

Triple Pentagon, 400, 800, 1,600, 2,000, 2,800, 3,200, 4,000, 4,400, etc. revs. per min.

Single Hexagon, 1,000, 2,000, 3,000, 4,000, 5,000, 6,000, 7,000, 8,000, etc. revs. per min.

Double Hexagon, 500, 1,500, 2,500, 3,500, 4,500, 5,500, 6,500, 7,500, etc. revs. per min.

Triple Hexagon, 333·3, 666·6, 1,333·3, 1,666·6, 2,333·3, 2,666·6, 3,333·3 etc. revs. per min.

Single Star, 200, 400, 600, 800, 1,000, 1,200, 1,400, 1,600, 1,800, 2,000, etc. revs. per min.

Double Star, 100, 300, 500, 700, 900, 1,100, 1,300, 1,500, 1,700, 1,900, etc. revs. per min.

Although there are several speeds for each figure, it is remarkably easy after very short practice to identify the actual speed by watching the figures as the machine is run up, and the writer has found the method most popular with students. It has been adopted by Prof. David Robertson in this country and by Prof. Kenelley, in the U.S.A., and is certainly by far the most simple and accurate method of standardising tachometers, for which purpose it was adopted by the principal tachometer makers during the war. It is specially suitable in its simple form for acceleration measurement during the starting and stopping of machines, the instant at which each figure becomes stationary being noted by the observer.

For rough tests of speed, a simple tuning fork with shutters struck or pinched by hand will serve, but it is better to have an electrically maintained fork. A mercury contact fork serves very well. A good form of fork with mechanical contacts, was developed by the Royal Aircraft Factory at Farnborough, and is manufactured by MM. Tinsley & Co. This fork has no shutter, but is provided with two mechanical contacts near the base of the fork, one for maintaining the oscillation and the other for connecting to the primary of an ordinary motor ignition coil, the secondary of which is connected to a Neon tube fixed near the rotating disc. The author uses this tube in a box containing two circular apertures and a 45° mirror, so that by looking down through the upper aperture the disc can be seen as if horizontal. With the Neon tube, however, there is only one flash per period, or 3,000 per min., from a 50-period fork, so that the speeds corresponding to the various figures are half of those given in the above table. It is a great convenience not to be obliged to look through the slits of the ordinary shutter fork.

As regards accuracy, there is no difficulty in adjusting a fork to about 1 part in 10,000, and it forms a most reliable standard as its temperature co-efficient is only between ·01 and ·02 % per 1° C. When great accuracy is required, care must be taken to maintain it with a definite amplitude of vibration, but this is unnecessary for ordinary engineering work, and the fork may be relied on with the same confidence as a good clock.

Roller Stroboscope for Speed, Frequency, and Slip Testing.— The objection to the single tuning fork stroboscope above described is that it will not serve for measuring speeds other

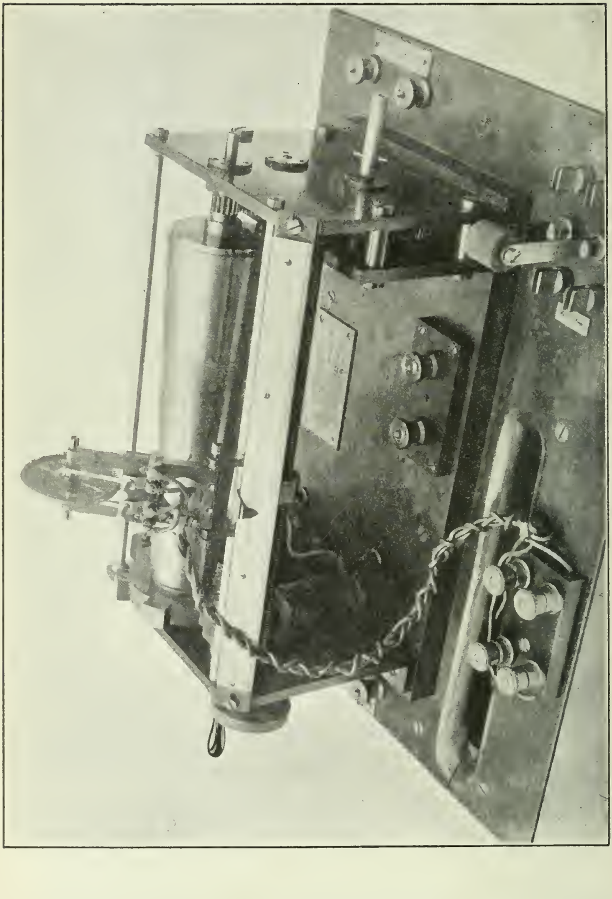
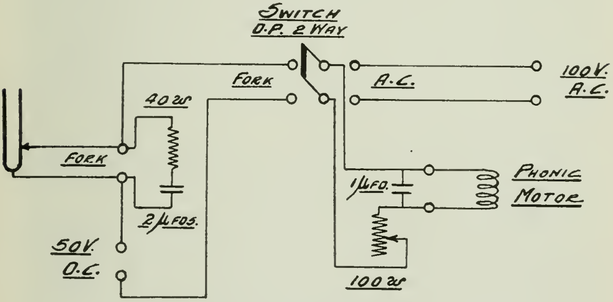


Fig. 9.

than those indicated in the table except by the laborious process of counting the apparent revolutions of the figure. In order to get over this difficulty and make the device capable of measuring any range of speed, the author introduced what he calls a roller or cone stroboscope shown in Fig. 9, and which may be thought of as a sort of speed potentiometer. In this apparatus a long cone of suitable taper is kept rotating at a constant known speed (usually 1,000 revs. per min.), and a light disc provided with say six radial slits is lightly pivoted in a frame which can be tranversed axially along the cone by means of a screw, the plane of the disc being at right angles to the axis of the cone. If the disc rolls on the cone at a point where the diameters are equal it will run at exactly the same speed as the cone (assuming no slip), and if the cone runs at 1,000 revs. per min. and there are 6 slits, there will be 6,000 flashes per min. exactly as from the fork itself. But by traversing the disc along the cone, the speed of the disc can be varied proportionately, and hence any speed can be balanced by traversing until the appropriate figure on the shaft of the machine under test appears stationary. In the stroboscope as usually made a movement of 1 cm. along the cone varies the speed by about 1%, so that the balance can easily be secured to a fraction of 0·1%. The cone is maintained at constant speed by a simple star wheel on the end with six poles running as a " phonic wheel " from the contact of the standard fork. Fig. 10 shows the connections for this purpose. On the other hand, if an asycronous alternating current motor is being



CONNECTIONS FOR OPERATING ROLLER STROBOSCOPE BY A.C. SUPPLY OR BY STANDARD FORK.

FIG. 10.

tested, and the phonic wheel magnets are excited from the supply, the cone will run at the syncronous speed, and the slip of the motor can be directly measured with great accuracy. The roller stroboscope was in fact first devised as a slip meter, but the addition of the tuning fork connection makes it a very accurate "speed potentiometer," the cone being analagous to the slide wire of an ordinary protentiometer and the tuning fork to the standard cell. It should be pointed out that the instrument is self-checking, as on looking through the slits of the revolving disc, to the poles of the phonic motor, the latter will appear stationary when the diameter of the disc and cone are equal, and the zero of the scale can consequently be checked and adjusted at any moment, while by setting a ring with various numbers of dots round the cone, the scale can be checked at various points. No trouble whatever has been experienced either from slip of the disc on the cone, or from wear, and the device has the further important advantage that it takes no power whatever from the machine under test, as nothing but the stroboscopic diagram is attached to it.

Brakes.—A large number of friction brakes of the Prony or band forms have been devised, but they are none of them satisfactory from the point of view of testing high speed motors. Prony or block brakes are the more accurate as the torque is directly balanced and there is no ambiguity about the measurement, but they involve special blocks for each size of pulley. Band brakes are more convenient, but when used on small pulleys there is some doubt as to the exact radius of action of the load owing to the camber of the pulley and thickness of the belt, and, as a rule, they have the further objection of putting a considerable lateral strain on the shaft and thus altering the bearing friction. All friction brakes are liable to variations of friction and consequent unsteadiness, and they also need water cooling, if used for more than a few minutes, which generally involves spray and mess.

Apart from these troubles also the waste of power is objectionable and friction brakes are obviously incapable of supplying mechanical power for testing generators.

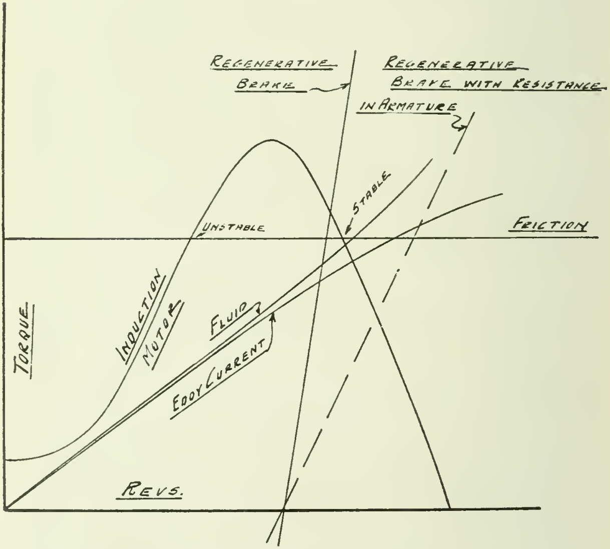
The Froude water brake is the most accurate of the purely mechanical dynamometers, but is somewhat costly. Eddy current brakes of various types have been devised and are effective and easily regulated. But an eddy current brake is after all only a short circuited generator, absorbing power in heating its own circuits, so that by replacing it by an ordinary generator we obtain the same characteristics with the added advantages of using a standard machine, of avoiding the need for cooling, since the power is taken off to be used elsewhere or returned to the mains, and of enabling the brake to be run as a motor and thus giving a known mechanical input for testing generators. The only disadvantage is the greater weight, but this is not of serious importance with machines up to 20 H.P. or more, while it can readily be overcome in larger machines, if desired by flotation.

Regenerative Dynamometer Brake.—The "cradle dynamometer" or balanced generator was first introduced for testing electrical generators by the Rev. F. J. Smith. When considering the best arrangements for motor and generator testing at the Northampton Institute in 1901, the writer made a review of the possible methods, and came to the conclusion that by far the best device would be to hang variable speed D.C. generator or motor from balance arms on knife edges, to provide for separate excitation with a long range rheostat, and employ a self-centering chuck for coupling to the machine to be tested.

The arrangement of the first testing outfit set up in the electrical engineering laboratory of the Northampton Institute was described in *Engineering* of November 24th, 1905. The generator was a 4-pole 8-K.W. Westinghouse machine designed to give 100 volts at any speed between 750 and 1,600 revs. per min. Two pairs of knife edges were mounted on brackets on each side of the machine, and coupling rods with hardened steel hooks were used to suspend it from a pair of balance arms on knife edges turning on a bracket from the laboratory wall. A pair of arms with additional knife edges from which weights could be hung were also fixed to the sides of the machine, and the distances of these knife edges from the centre was so adjusted that a 2 lb. weight hung from the outer knife edges represented a power of 1 B.H.P. for a speed of 1,000 revs. per min., while a 3 lb. weight hung from the inner knife edges represented 1 K.W. at the same speed. A telescopic shaft was coupled to the machine with a self-centering chuck C at its further end. The machine to be tested was mounted on slide rails on a rising and falling table actuated by screw gear from a handwheel at the side of the pit. Special arrangements were made for lining up the test machine with the balanced generator, but these will not be described, as further simplifications have since been made. This arrangement proved very sensitive and convenient and a large series of tests was made with it, some of which will be described below. The machine to be tested was mounted on the table, lined up and coupled, and run up to speed, after which the balanced generator was excited until its voltage was equal to that of the supply and then switched into parallel with the mains. Raising the excitation then caused the generator to send current into the mains and load the motor under test, while decreasing the excitation caused the brake to run as a motor and transmit mechanical power to the test machine.

After the required load had been hung on one or other of the knife edges it could be balanced by regulating the excitation, and the balance was remarkably steady, as any variation of the main supply voltage usually affected both machines similarly. Another advantage of this type of brake is in determining starting torques. By short-circuiting the generator brushes, the machine is converted into a low resistance eddy current brake giving a very large torque when the machine simply crawls round, so that the starting torque can be accurately measured when the machine is just moving and a true average obtained.

An important question in connection with brakes to which little attention appears to have been given is that of their inherent stability. In Fig. 11 torque-speed characteristics are given for various forms of brake—for example, the ordinary friction brake



Torque-Speed Characteristics for Machine & Brakes.

Fig. 11.

has a torque which is approximately independent of the speed, while in fluid and eddy current brakes it is proportional to the speed for low values and bends upwards in the former due to turbulence, and downwards in the latter due to heating at high speeds. Now if we are testing a machine balance is obtained when the torques developed by the machine and brake are equal, but if the slope of the torque-speed characteristic of the machine or $\frac{\delta T}{\delta n}$, is greater for the machine than for the brake the balance will be unstable, and this may easily be the case with a simple friction brake, giving rise to that swinging over which has proved a frequent source of trouble and for which various methods of compensation have been devised. The same trouble may be experienced to a lesser extent with fluid or eddy current brakes. But the regenerative brake is essentially an eddy current brake of low resistance, and its torque-speed characteristic is, therefore, extremely steep. This form of brake is consequently stable in all practical circumstances, and its stability can be regulated to any extent desirable by introducing resistance into the armature circuit. This may sometimes be desirable when testing on an unsteady supply, although in most circumstances it can be arranged that fluctuations in the supply affect the machine and brake nearly equally, so that no appreciable disturbance is introduced.

The electrical arrangements will be described later, but the device proved so accurate and convenient that it was decided to make it in a more self-contained form, so that the whole brake could be moved and coupled to any machine *in situ.*

Portable Regenerative Dynamometer Brake.—Fig. 12 shows a 3 B.H.P. portable dynamometer of a type originally constructed at the Northampton Institute, and which has since been manufactured by MM. H. Tinsley & Co. It consists of a rectangular framework standing on pillars which can be provided with castors, and which form guides for an inner framework in which the generator is suspended from knife edges. In order to secure the greatest rigidity and definiteness of position of the generator axis, the vertical rods carrying the hard steel hooks on which the generator knife edges rest are carried both up and down, and two frames forming the balance arms are provided above and below the generator respectively. The upper frame has a travelling weight on it which is traversed by means of a guide screw, and the weight is provided with two pointers reading on scales at the front and back of the brake respectively. One of these scales reads the torque in pound—feet and the H.P. at 1,000 revs. per min., while the other gives the torque in metre—kilograms and the power in kilowatts for 1,000 revs. Additional weight can be hung from the end of the balance arms, both for calibrating the scales and extending the range. A screw and

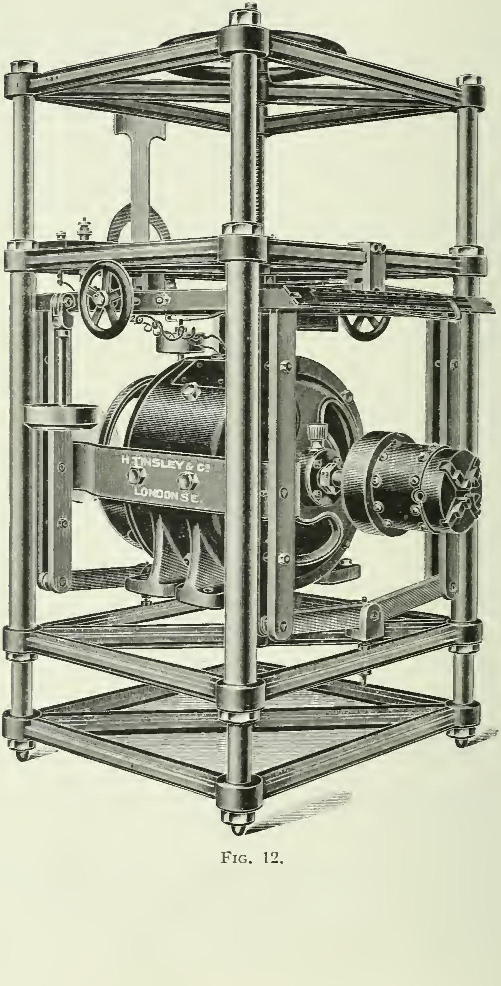


FIG. 12.

handwheel at the top of the brake allows the inner case to be raised and lowered for lining up, and the generator spindle is provided with a flexible coupling and self-centering chuck at one end, and a stroboscopic disc at the other. This brake has been found remarkably convenient and sensitive and a large amount of work has been done with it. Its power is small, but as will be seen below it enables machines up to 15 or 20 B.H.P., to be tested by measuring their losses, besides providing for direct tests up to 3 B.H.P. There would probably be no great difficulty in making a brake of this form for 20 B.H.P., which would test the losses of machines up to 300 K.W. or more.

Fig. 13 shows a small $\frac{1}{4}$ B.H.P. brake of this type designed for testing small motors, and for the measurement of iron losses in armature cores. It has proved remarkably sensitive as it develops a maximum torque of 10,000 gramme cms. and will detect 1 gramme cm.

Transmission Dynamometers.—Although a large amount of work has been done on such dynamometers since the original dynamometer coupling of Ayrton and Perry in 1873, we are still without a reliable and easily obtainable transmission dynamometer. The importance of such a device is obvious as it bears the same relation to mechanical power supply as the wattmeter to electrical supply, and it is surprising that no instrument has yet been put on the market which will indicate the power in a line of shafting. Such transmission dynamometers as have hitherto been used are not power meters but torque meters, their indications having to be multiplied by the speed to give the power transmitted. They all depend on the original principle of Ayrton and Perry of having a spring coupling and employing some device to indicate the twist of this coupling while the shaft is rotating. Ayrton and Perry, and von Hefner Alteneck employed levers for this purpose, and others have employed stroboscopic devices with fair success. A simple device which has been considerably employed is to use two knife-edge contacts on the halves of the coupling in series with a battery and telephone, and to rotate one of the brushes until contact is simultaneously made on both.

Owing to the undesirability of splitting a main shaft, it is desirable, if possible, to use the twist of a certain length of the shaft itself for measuring the torque, and this as a rule demands very fine measurement. Probably the best method of doing this has recently been devised by one of the author's colleagues, Mr. J. M. Ford, who has applied his "induction micrometer" to the purpose. In this device a laminated iron core wound with a secondary winding moves in a small gap, between two similar laminated electro-magnets oppositely

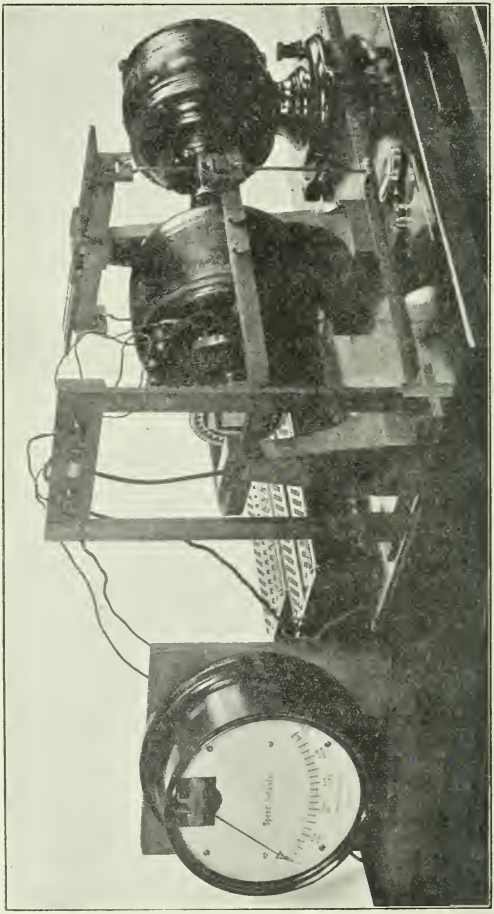


FIG. 13.

excited by two primary windings in series, and fed with interrupted current from a battery and a tuning fork. If the iron armature is exactly between the two magnets, no E.MF. is generated in its winding, but a very small displacement strengthens the effect of one magnet and weakens the other producing an E.M.F. which is indicated on a pointer galvanometer connected to a thermo junction.

Direct Reading Transmission Dynamometer or Mechanical Wattmeter.—The ideal transmission dynamometer would be one which automatically multiplied the speed and torque and indicated the power directly on a dial. There is no difficulty in principle in obtaining such a dynamometer, and the writer devised one or two forms as early as 1894, which would probably have functioned fairly well had they been made. One only of these will be mentioned here as it exhibits the principle which is certainly the correct one for any devices of the kind. If we have an electrical generator excited by a constant field, the E.M.F. developed in the armature is rigidly proportional to the speed. If therefore, we can further arrange to make this E.M.F. vary, or tap off a portion of it proportional to the torque, the P.D. will be proportional to the product of the speed and torque and hence to the power, which can thus be directly indicated on a voltmeter. This is the principle which was recognised from the first, and one of the simplest methods of realising it was to mount a simple Gramme ring armature on one half of a spring coupling, and its commutator on the other half, connection between the armature and commutator being made by flexible wires. By employing a permanent magnet to give the armature field and fixing a pair of brushes on a line perpendicular to the neutral axis, no E.M.F. will be collected when there is no twist on the coupling, but if the coupling is twisted through an angle θ, the P.D. between the brushes will be proportional to $n \sin \theta$, or to $n\theta$ if θ is small. Since θ is proportional to the torque T in a spring coupling, the P.D.V $= KnT = aP$ where K and a are constants and P is the power transmitted, and the voltmeter scale can be directly marked off in HP or watts. Another way of obtaining the same result would be to employ two similar armatures on the halves of the coupling with the sections of their windings connected in series and in opposition. Then any twist of the coupling would produce an E.M.F. proportional to the torque and to the speed.

As no opportunity was found for having such dynamometers constructed, the matter was left in abeyance for some years, and when it was revived, the possibility of eliminating the commutator or sliding contacts was considered. This can readily be done by substituting inductor alternators for the D.C. machines, and Fig. 14 shows a form of transmission dynamometer coupling which was patented in 1910. The spring coupling consists of two ordinary half couplings connected together by a cage of steel rods or strips so as to give a twist of a few degrees at maximum torque. On the bosses of these two couplings are fixed two laminated inductors of rounded star form, usually with six or eight poles. Two laminated slotted armatures surround these inductors and are fixed in two cast

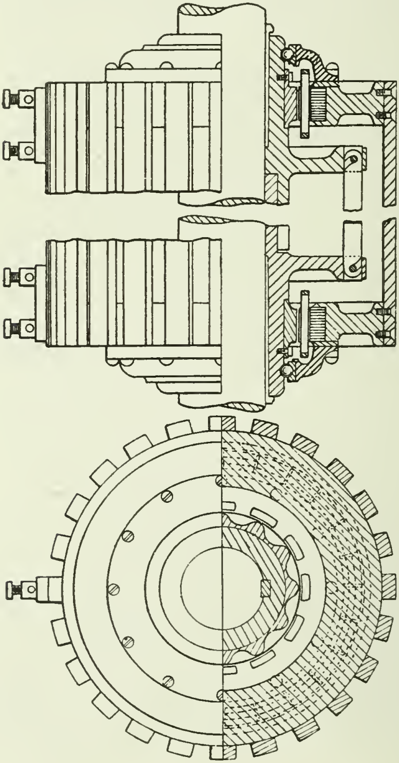


Fig. 14.

iron rings the outer surface of which are joined together with a number of bar magnets, forming a stationary outer case, which is supported on ball bearings from the couplings; the magnetic flux from the magnets traverses both armatures and inductor, and the magnetic circuit is completed through the shaft which is made in telescopic form in order to secure both a satisfactory alignment and a good magnetic joint. The operation of both alternators by the same magnetic field is of importance, as in the event of the permanent magnets weakening with age the balance of their E.M.F.'s is not destroyed. The principle of the device is quite simple. Let each of the alternators develop an E.M.F. $E_1 = E_2 = Kn$, the two E.M.F.'s being in phases when there is no torque on the coupling. Then if they are connected in series and in opposition the resultant E.M.F. will be obtained by the base e of the vector triangle of which E_1 and E_2 are the two sides and the included angle θ is the phase difference between them which is proportional to the torque. It is evident that

$$e = 2E \sin \frac{\theta}{2} = E\theta \text{ for small angles,}$$

so that e is proportional to the product of the speed and torque or to the power transmitted, and it can be indicated on an A.C. Voltmeter

$$\text{Since } \sin \alpha = \alpha - \frac{\alpha^3}{6} = \alpha(1 - \frac{\alpha^2}{6}),$$

$\sin \alpha = \alpha$ within 1 % up to $\alpha = 0 \cdot 245$ radian or about 14°, so that θ may be 28°, and if the inductor has 8 poles the maximum torque should produce a twist of $28/8 = 3 \cdot 5°$.

Although any ordinary high resistance voltmeter with negligible frequency variation would be suitable for such a dynamometer, the square law is objectionable, and two special forms of indicating instrument have been devised. The most simple of these is a plain induction instrument with two shunt electro-magnets connected to the two alternators and acting on an aluminium disc. The torque on such an instrument can easily be shown to be proportional to $V_1 V_2 \sin \phi/f$ where V_1 and V_2 are the voltage of the two machines ϕ the angle of phase difference between them and f is the frequency. Since V_1, V_2 and f are all proportional to the speed, the torque on the disc is proportional to $f \sin \phi$, or to $f\phi$ if ϕ is small, and hence it is proportional to the product of the speed and the torque on the dynamometer coupling. If therefore the disc is controlled by a spring the deflection will be proportional to the power, and a braking magnet can be provided for damping as in ordinary induction instruments.

The objection to this type of indicating instrument as with all deflectional induction instruments is its large temperature variation due to the high temperature coefficient of the disc, but if we remove the control spring it makes an excellent mechanical energy meter for integrating or metering the total mechanical energy supply over any period, as although the driving torque is affected by the temperature variation of resistances of the disc, the braking torque of the permanent magnet is similarly affected, and the speed of rotation of the disc is independent of temperature. Another form of indicating instrument which overcomes this difficulty, and has the added advantage of allowing for changing the range as desired, is of the moving coil form with a rectangular formerless spring-controlled coil rotating round a laminated iron core between the poles of a laminated electro-magnet excited by two coils connected to the two alternators; the moving coil, in series with a non-inductive resistance, being connected to two of the alternator terminals so that the current through it is proportional to the vector difference *e*. It will be seen that if the two magnetising coils assist one another the gap flux is proportional to the vector sum of the E.M.F.'s, or to E cos $\phi/2$ divided by the frequency so that it will be practically constant and in quadrature with E_1 and E_2, so that it is in phase with the flux, and the torque on the moving coil will therefore be proportional to *e* or to the power, provided that the series resistance is sufficient to swamp its reactance. By doubling the resistance of the moving coil circuit the deflection is halved or the power range doubled and so on.

Any of these devices can be calibrated either directly on a brake such as the regenerative dynamometer above described, or indirectly by subjecting the coupling to a known static torque, clamping it in that position and rotating it at a known speed. It is of course necessary that the armature should be so set as to be exactly in phase for zero torque, and this can be effected while running on the testing brake by turning one of the armatures slightly in its seating, provision for which is arranged.

Owing to various vicissitudes this dynamometer coupling has never been completed, although parts of it have been constructed, but it appears to be so sound in principle and easy of construction that it most certainly ought to be developed as a standard device, which will give the mechanical engineer a wattmeter or energy meter comparable with electrical wattmeters or energy meters, and enable continuous records to be kept of the power in lines of shafting, etc. It is readily convertible into a pulley dynamometer by extending one of the half couplings over the magnet case to form the pulley and in the case of long shafts conveying considerable power as in propeller shafts, the shaft itself can be used as the spring coupling, provided that the alternators are made with a large number of poles so that a small amount of torsion produces a sufficient phase displacement.

III.—Connection and Arrangement of Testing Plant.

Having dealt with the chief items of a testing plant, we come to its connection and assembly, and in order to save space we will deal at once with arrangement suitable for testing either D.C., single phase, two-phase, or three-phase machines. There are therefore only two outfits to be considered, one for testing electrical, and the other for testing mechancial output or input.

Electrical Supply.—Where a direct current supply is available by far the most convenient machine for use with a testing plant is a rotary converter with six slip rings giving single phase, two phase and three phase supply. This type of machine has the advantages of being much less costly than a motor-alternator of similar output, as it only involves one machine instead of two ; and that machine may be relatively small, as the armature winding only carries the difference between the input and output current. It usually has a fairly closely sinusoidal wave-form owing to its distributed winding, and there is no difficulty in obtaining a machine which will cover most commercial frequencies by change of excitation. The only objection to it is that it provides no voltage variation, but a small range may be provided on the D.C. side, and larger changes by employing transformers with suitable tappings. Frequency regulation may be effected on the exciter rheostat by the aid of a reed or other frequency meter or a stroboscopic disc on the shaft.

Electrical Testing Connections.—Fig. 15 shows the connection of the motor testing panel at the Northampton Institute, which there seems no reason to modify after long experience except by extending the principle to multi-range ammeters as soon as they are available. Eight switches are provided at the top of the board for D.C. single, two, or three phase supply and make connection to two or more of four main leads 1, 2, 3, 4, running to four terminals to which the machine under test is connected. Ammeters are connected in leads 1, 2, and 3, the main coils of a double multi-range wattmeter in 1 and 2, and a multi-range voltmeter is connected to a multiple switch enabling the P.D. between any pair of terminals to be measured. One of the wattmeter shunts is connected between terminals 1 and 3, and the other between 2 and either 3 or 4, the change being effected by a small throw-over switch. This arrangement makes the wattmeter direct reading with the same constant whatever form of supply is used as will be seen in a moment. In fact so far as power measurement is concerned, it is not even necessary to know the kind of supply.

For D.C. testing the machine is connected to terminals 1 and 2.

For single phase A.C. the machine is connected to either 1 and 2, 1 and 3, or 2 and 3.

For 3 phase A.C. the machine is connected to 1, 2 and 3, and the wattmeter shunt switch is thrown to the left.

For 2 phase A.C. the machine is connected to 1 and 3, and 2 and 4, and the wattmeter shunt switch is thrown to the right.

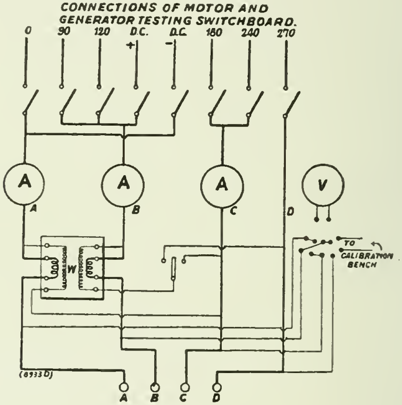


FIG. 15.

It is evident that when the wattmeter shunt switch is thrown to the left, the wattmeter reads the total power supplied by leads 1, 2 and 3 in all circumstances. For example in the case ot D.C. or single phase supply, if leads 1 and 3, or 2 and 3 only are used, one or other half of the wattmeter only is in action, but as the two systems are similar, there is no difference in the indication. On the other hand if leads 1 and 2 are used, both wattmeter systems come into operation, but the current in the moving coils is halved for the same P.D. as the two pressure circuits are in series. When leads 1, 2 and 3 are used with the wattmeter shunt switch to the left we have the ordinary double wattmeter connection for three phase power measurement, while if the switch is thrown to the right the two systems register the power supplied by leads 1 and 3, and 2 and 4 respectively, and the wattmeter therefore reads the whole power if the two phase circuits are independent. This matter is of the greatest importance as it shows how a moderate amount of apparatus can be permanently assembled to cover every kind of electrical power measurement without moving or damaging the instrument. With a double wattmeter of the form described above for 100 amperes per system machines can be tested from $\frac{1}{4}$ B.H.P. or kilowatts to 20 K.W. at 100 volts and proportionately up to 2,000 or 3,000 volts between lines, so that generators up to 500 K.W. or motors up to 600 B.H.P. can be tested at the higher voltage without disturbing any instruments except the ammeters. By employing multi-range ammeters this difficulty can also be surmounted, and it is proposed to employ a single commutator to change the range of the wattmeter and ammeter simultaneously.

Checking of the instruments *in situ* is allowed for on the board. A pair of P.D. leads is brought from the standardising bench to an extra pair of contacts on the voltmeter selector switch, so that by merely throwing over these contacts, the voltmeter can be calibrated without removal. Similarly, two current leads are brought from the standardising bench to terminals on the board, and these can be connected to the main circuits so that the ammeters and wattmeter can be checked in place. As the changes of range of the instruments are very accurate a list of the percentage errors at each point of the scales can be obtained with a few checks at some standard frequencies, and high accuracy can thus be obtained with inexpensive instruments, as they are never disturbed.

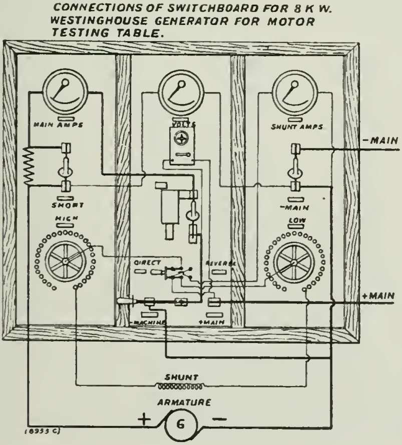


Fig. 16.

The panel for regulating the regenerative brake is shown in Fig. 16, and carries the usual starting arrangement and automatic circuit breaker, and in addition a long range regulating rheostat for regulating the excitation, a paralleling voltmeter, and a reversing switch for changing the direction of rotation. A throw over service also enables the armature to be short-circuited for torque test.

In the case of transformer testing, all that is required is two boards with the above universal arrangement of connections and D.C. Single phase or polyphase transformers or converters can then be directly tested. A transformer bench on these lines for transformers up to 2,200 volts between lines was constructed at the Northampton Institute and found satisfactory. The secondary load can either be absorbed in resistances or preferably be returned to the mains by suitable " loading back " arrangements which will also permit of the power factor of the load being easily varied. Owing to the large range of the instruments, no load and short circuit tests of the transformers can be made without difficulty.

DISCUSSION.

Dr. F. B. Young said he wished to thank the Society for the privilege of listening to Dr. Drysdale's extremely interesting and valuable paper. There could be no doubt as to the importance of detailed analysis of the energy losses in electrical plant to those engaged in the improvement of design. Unfortunately, not being an electrical engineer and in particular having had no experience of commercial production, he could not express any opinion as to the adequacy of the methods in practical use. Recent experience, however, with regard to physical apparatus had suggested that manufacturers were not always sufficiently alive to the importance of the test-room and sometimes fail to take advantage of the up-to-date appliances available. As instances might be mentioned the offer of ammeters having errors of 5 or 6 per cent. and the supply of glass in a state of severe strain. The latter event could have been avoided by the systematic examination of all articles with the aid of polarised light. Saving of costs in the test-room might prove the most extravagant of economies.

Mr. W. B. Esson, M.Inst.C.E., F.S.E., said he had listened to Dr. Drysdale's interesting address with great pleasure. It was a long time since he had done any testing of small motors and the appliances which Dr. Drysdale had devised and designed for the purpose, seemed complete and efficient. The fine instruments which were on the table reminded him forcibly of the days when, with other students, he had worked in a basement under Cowper Street School in Finsbury, trying to gain some knowledge of the then new subject of electric lighting and transmission of power. That was 40 years ago, and the instruments at their disposal were then neither numerous nor easy to work with. But they got results and they had Professor Ayrton guiding their efforts, while for chief demonstrator they had Dr. R. M. Walmsley, who was now the Principal of the Northampton Institute. That basement constituted the nucleus of Finsbury Technical College, before the college was built and many electrical engineers of to-day had pleasant memories of the work done there when the electrical industry was young.

It was nearly forty years ago since he had entered the works of Messrs. Paterson & Cooper as manager, and had taken a hand in the making of commutator ammeters and voltmeters, arranged with "series and parallel" barrel commutators such as Dr. Drysdale had described. They were permanent magnet instruments for continuous current and the coil encircling the soft iron needle consisted of ten strands which could be coupled up in series or parallel as desired. The instruments were designed by Ayrton and Perry, who insisted on a high degree of accuracy; they had a straight line law, *i.e.*, the deflections were proportional to the currents flowing, and they furnished for several years the only portable instruments electrical engineers could really rely on. He thought in expressing such a high opinion of the accuracy of old time instruments, Dr. Drysdale must have had these instruments in his mind. As regarded present day instruments Dr. Drysdale had not such a good opinion, but of course, one had to discriminate between commercial instruments and instruments designed for testing purposes. For the former, which were mostly employed as indicators for the guidance of attendants, a higher degree of accuracy than, say, was furnished by a steam gauge, was not necessary, but for testing instruments considerable accuracy was needed. He did not remember the limit of error allowed in instruments by the Standards Committee, but the point he had referred to had to be kept in mind.

Dr. Drysdale had mentioned various forms of tachometers. One of the most handy forms for workshop use was a little centrifugal pump, the sort of tiny brass pump used for oil circulation, with glass upright tubes on the suction and delivery sides. If the tubes were half filled with water, when the pump was driven the level rose in one tube and fell in the other and the speed was exactly indicated by the difference of level. If the water were coloured and a graduated white lath were placed behind the tube in which the water rose, the speed could be observed by a man controlling a stop valve or a rheostat at a considerable distance. The ordinary engine tachometer or the Young's speed indicator were good in their way; the latter was a handy little instrument, but it wore out rapidly if run continuously coupled to a motor by a helical spring as was often done in testing. It did not matter whether the pump wore out or not, that only meant remarking the white lath which could be easily done, while the pump could be run continuously. He (Mr. Esson) could quite understand the stroboscopic disc method of observation being popular with students, they had as a rule plenty of time in their hands and they had a traditional inclination towards colour and fireworks, but he doubted if Dr. Drysdale would give it as his considered opinion that the stroboscope formed the most convenient workshop instrument. There again they had to discriminate between engineer's instruments and physicist's instruments and though he had nothing but admiration for the ingenious and efficient appliances used by the author, it had to be admitted that many of them required the most careful preparation and setting up and were therefore only suited for quiet laboratory work. Moreover, the disc form of stroboscope, though all right for small motors, did not give what was wanted when testing on the grand scale. They had in such cases no time for the speed to settle down to this or that figure, but had to take observations on all the instruments when the whistle was blown, speed indicators included. They, therefore, needed an instrument which gave the exact speed at every moment.

As regarded dynamometers, the author's remarks interested him greatly and he well remembered early in his career rigging up a "cradle dynamometer" to test the power given to dynamos. Whether absorption or transmission dynamometers were used, torque was the thing being measured, but as Dr. Drysdale pointed out, there was no efficient and at the same time practical way of observing the torque transmitted through a short solid shaft, much less was there any way of observing the product of the torque and speed. In the Ayrton and Perry transmission dynamometer described, the levers actuated a pointer at the end of which was a polished bead and the torque could be got by measuring the diameter of the circle of light formed by the bead when the shaft revolved, and multiplying that by an ascertained co-efficient. In measuring the diameter, the rule frequently came in contact with the bead, but that was mere clumsiness and did not detract from the neatness and cleverness manifested in the device. But the device entailed a coupling, *i.e.*, cutting the shaft in two, and that damned the contrivance and for all time it settled the fate of transmission dynamometers, at any rate for use on a grand scale. It was therefore, fortunate perhaps, that there was no demand for such appliances. No doubt on occasions it might be desirable to make provision in a line of shafting for inserting some form of dynamometer to ascertain the power being transmitted, but that was the exception not the rule. In a turbine-generator, for instance, no one was interested in ascertaining the exact H.P. transmitted through the shaft. The electric power appearing at the terminals could be measured, the copper loss in the armature and fields could be ascertained and the hysteresis and eddy current losses could be calculated, not absolutely, but with fair approximation, and there they had, near enough, the shaft-horse-power. The criterion of performance was steam put in at one end of the system and B.O.T. units coming out at the other, and knowledge of the exact H.P. would, of course, make no difference to that result. He was now speaking as an engineer and the author would understand that. He would in conclusion say that even if some of the interesting methods described had little practical value, they had inestimable value in that they taught students to think and that after all was one of the most important things. He thanked the author again for his most interesting and instructive address and trusted he would soon give them another.

Prof. W. C. Clinton, B.Sc., A.C.G.I., M.I.E.E., said Dr. Drysdale's name had been associated for many years with most of the ingenious testing devices shown that night and he was to be congratulated on the originality and inventiveness shewn in their conception and execution. The majority of these methods would be suitable for research work or testing conducted with the object of effecting improvement in design. For small and moderate sized machines this work was practically finished many years ago, so that ordinary routine testing could be and was conducted in ways that didn't require such an expensive or elaborate equipment as that exhibited. For instance, nobody but a designer was concerned with the slip of an induction motor unless it were so large as to become serious, when it could be measured by tachometer readings.

At the same time he did not desire to minimise the importance of having accurate testing methods available when they were really needed.

Mr. Joseph M. Ford said he wished to refer to Dr. Drysdale's transmission dynamometer. It was unfortunate that that device necessitated the splitting of the shaft, which, although in order for certain testing work, would be inadmissible in tests of an assembled plant. Mr. Esson had said that there was no demand for a mechanical "watt-meter." This was not correct, since in ship's shafts, for example, the use of a transmission dynamometer of the torsion type was frequently the only method by which the power supplied to the propellor could be ascertained. This was outside the scope of the paper, but it was mentioned to show that there was a need for such an instrument as Dr. Drysdale proposed. It would undoubtedly be of great assistance in testing work, and an interesting point was that it would give the true mean power.

Certain torsion indicators give a " spot " reading only, and whilst this was correct when the torque was known to be absolutely uniform, serious errors might be introduced if there were any cyclic variations in the twist. In this respect, therefore, the type described appeared to be on the right lines.

Dr. E. H. Rayner, D.Sc., said he hoped that Members of the Society, who were particularly interested in the commercial side of the testing and use of plant, would have given their views on the subject of the suggestive paper by Dr. Drysdale, rather than those who were more particularly interested in the design and use of instruments.

His own work and that of Mr. Spilsbury, was largely concerned with the finding out and measuring of the errors in all kinds of instruments, such as those which had been described, so that they had to be able to calibrate very accurately any instrument which was sent to be investigated. The errors naturally varied with the type of instrument and for the purpose for which it was to be used, and the highest quality of instruments, such as were exhibited that evening, required all the accuracy available in their instruments and all the skill in their use that they could apply.

Speaking to the members of a Society who were particularly concerned with the general running of plant, he wished to bring forward a point which he felt was of considerable importance as regards the rating of what was classed as industrial electrical plant, such as generators and motors up to a few hundred horse power. The rating of electrical plant was being seriously considered from the point of view of international agreement as to standards of performance, and the most important criterion which it was practicable to adopt was a limitation of temperature rise at the rated power of the machine. The international standards, which would be largely incorporated in national standards, would specify temperature limits for the different parts of the machine, and manufacturers would develop their designs largely in accordance with the said limits, economising material wherever this could be done. It would be noted that in rating machinery in such a manner there was no recognised efficiency; it was left to the buyer to specify a figure for efficiency or not as he thought fit. His object in referring to the matter was that it might be far from sound policy to buy machines standardised in such a manner without reference to the type of load under which it would work. If a machine had to work for several hours a day throughout the year, the amount of energy wasted in heat might well be greater than the cost of the machine, and it would therefore be more economical to pay considerable attention to the actual efficiency of a machine, and, if necessary, to use a more liberally designed and larger one in order to reduce the loss of transformation of electrical into mechanical power, or *vice versâ*. This was a case for the application of Kelvin's Law so as to give the least annual cost, taking into account the cost of capital, depreciation, cost of power supplied, and cost of power wasted.

On the subject of particular types of instruments, Dr. Drysdale had advocated the use of ammeters of the moving-iron type for continuous currents. The speaker had not had the pleasure of seeing his instruments, but would suggest to members that they should be careful before using ordinary commercial moving-iron instruments in this manner. He considered that they were far more liable to error than the ordinary type of moving coil permanet-magnet instruments. He would also like to point out that alternating current ammeters were comparatively unimportant instruments, as a measurement of the current alone did not give an accurate idea of the power in an alternating current circuit, unless the phase relation between the voltage and current were known. The watt-meter was therefore a far more important instrument than the ammeter in alternating current work.

As regards the measurement of alternating power, he strongly recommended the consideration of the use of a voltmeter with a single range of 5 amperes suitable for 110 volts, with additional resistances so as to make it suitable for direct connection to the standard voltage of about 440. For any currents above 5 amperes, such an instrument was used with current transformers, the primary of which might be of any convenient value to suit the load in question, which might be from 10 amperes to 10,000 or more. For higher voltages, potential transformers were used, wound on the primary side to suit the particular voltage in question, the secondary voltage being always about 110 volts. Such a watt-meter became in this manner a universal one for alternating current power measurement, whether it were used direct for measuring 0·5 kilowat with full scale deflection, or whether it were used with potential transformer and current transformer for 20,000 volts and 1,000 amperes, in which case, it would read with almost equal accuracy a load of 20,000 kilowatts. The use of the instrument transformer caused small additional errors due to phase angle and errors in ratio, but these could be determined and allowed for.

Although he had great admiration for Dr. Drysdale's development of the alternating current potentiometer as a laboratory instrument for research work, he would not like to have to measure by its means the efficiency of a 3-phase machine such as he had shown, even if the frequency were far more steady than could be expected of ordinary supply circuits. He agreed with Dr. Drysdale that electrostatic methods were unsuitable for ordinary commercial work, although of the greatest value for precision calibration purposes.

Mr. William Brooks Sayers wrote that the subject of the paper was of peculiar interest to him as he was engaged on the development of a new type of dynamo in which the various sources of loss of efficiency were reduced in the aggregate by about one half. Although electrical engineers had been justly proud of their achievements in the way of power for weight of apparatus, say in the case of high power motors, yet if one attempted power transmission by means of generators and motors he sadly realised that 89 per cent. of 89 per cent. is under 80 per cent., and that 20 per cent. to 30 per cent. of his dearly bought brake-horse-pwer would be wasted in heating up the generators and motors and in circulating air to get rid of heat. In order to remedy this state of affairs and enable designers to determine economical relations and proportions of constituent parts, it was essential as Dr. Drysdale said to be able to measure the various losses separately. This was appreciated in a paper read by the speaker before the Institution of Engineers and Shipbuilders in Scotland in 1902 (Vol. XLVI., p. 217 to 247). So far the tests of the new type of dynamo had been made on the Hopkinson principle of coupling two machines together mechanically and reducing the field excitation of one to get a load, but the various sources of loss had also been measured by means of the motor current, the motor characteristic being known, and the power measured to drive one armature first without excitation and then with several degrees of excitation. The method of mounting the motor machine on knife edges and directly measuring the torque transmitted to the generating machine was good and the speaker hoped to make use of it.

A demonstration of the interesting features of the speaker's new machine may be seen by members of the Society of Engineers by appointment.

Reply by the Author.

Dr. Drysdale in reply to the question of the accuracy of instruments raised by several of the speakers, said he had in mind more particularly his experience nearly 30 years ago in connection with the manufacture of comparatively simple and inexpensive soft iron instruments, and it was certainly then possible to make these instruments with less than 1 per cent. error, in fact, no instrument was passed with a higher error. Subsequent experience with similar instruments after several years' service had shown that they still retained practically the same accuracy, and he thought it was a decidedly retrograde step to permit any lower degree of accuracy except for rough switchboard purposes.

Mr. Esson had mentioned the Ayrton and Perry commutator, ammeters, and voltmeters, which were excellent instruments ; and the series parallel commutator employed with them was of considerable value. He had not intended himself in any way to claim the invention of the series parallel commutator, but what he had done was to modify it to give intermediate ranges and also to apply it to alternating current instruments where special care was necessary in order to obtain accurate ratios in view of the inductances and magnetic effect of the separate circuits. It was specially in connection with alternating current measurements that a wide variation of range was desirable, and he considered that this was a matter which should specially engage the attention of instrument makers.

With reference to Mr. Esson's remarks to tachometers, there could be no doubt that the stroboscopic method was extremely convenient for commercial testing, as it avoided the necessity for attaching anything to the machine except a simple disc, while the accuracy was beyond question. The roller type of stroboscope did not require any time to be given for the settling down of the speed, and a reading could be taken at any moment. As a matter of fact, students were generally concerned with using methods which were as rapid as possible as their laboratory time was restricted to certain periods, and there was a liability for their work to be thrown away if the experiments could not be conducted in the given time.

On the subject of dynamometers both Mr. Esson and Mr. Sayers appreciated the cradle dynamometer method of testing, but Mr. Esson did not appear to consider that a transmission dynamometer would be of much value. Certainly the form of transmission dynamometer hitherto devised did not offer much temptation to the general user, but it seemed too much to say that there would not be a considerable demand for transmission dynamometers if they could be easily set up and be made to give direct reading on a dial like an electrical wattmeter. In the

Ayrton and Perry instrument, which was the parent of all transmission dynamometers, it was difficult to obtain the position of the revolving bead to a high degree of accuracy, and it was even then necessary to multiply the torque by the speed to obtain the power transmitted. He agreed with Mr. Esson as to the undesirability of cutting the shaft except in the case of ordinary line transmission, but there seemed no reason why, in the case of fairly long shafts the two portions of the electrical device described in the paper should not be mounted so as to make use of the twist in the shaft itself, as has already been done in several electrical torque-measuring devices used on propeller shafts. Mr. Ford had called attention to the importance of such measurements. It would be, of course, practically impossible to make use of such a device in an ordinary coupled turbo-generator set where no great length of shaft was available. On the other hand, the desirability of making separate determinations of the efficiency of the prime mover and alternator seemed indisputable, as calculation was insufficient to determine the efficiency of the alternator with certainty.

Mr. Ford's remarks concerning the importance of transmission dynamometers which gave an average reading of the power, rather than the spot reading at a certain point of the revolution, ought to be borne in mind, as in many cases the turning moment might be so uneven as to make a spot reading of little value.

Referring to Dr. Rayner's remarks, and dealing first with his points concerning measuring instruments, Dr. Drysdale agreed that the permanent magnet moving coil instrument was by far the most satisfactory type of instruments available, but this special point in the paper had been to consider the employment of a universal arrangement of testing plant suitable both for direct and alternating current machines, and for this reason he had turned his attention to the improvement of the ordinary soft iron instrument. Dr. Rayner had pointed out that for alternating current working accuracy of the ammeter and voltmeter was of minor importance, and this was true, as, if a satisfactory wattmeter were employed, it served equally well for the absolute power determination for both direct and alternating current machines, so that soft iron instruments of a moderately high degree of accuracy was sufficient in either case. On the other hand, he did not agree that the accuracy of the ammeters and voltmeters was of little importance, as besides determining the efficiency and losses in the machines, it was desirable to know their power factor, and for this purpose fairly accurate determinations of the P.D. and current were desirable. He agreed with Dr. Rayner concerning the objection to using an A.C. potentiometer for testing large alternators, although, if such machines were tested, they were generally kept fairly steady for some time, and there would be comparatively little difficulty in taking the potentiometer readings. He had put forward the method because his own experience had led him very much to doubt the advisability of using transformers in connection with wattmeters. He had tested a large number of instrument transformers, and practically all of them had shown fairly large phase displacements, so that he had not been able to trust them for use with wattmeters. Apparently, however, Dr. Rayner's experience had been more favourable, and there appeared to be one particular maker who supplied a combination of instrument transformers and wattmeter which were were exceedingly satisfactory. In such a case he would have no hesitation in recommending this method as far more convenient than the potentiometer method, but a strong warning should be given against trusting to tests made with current transformers unless it was certain that these errors had been eliminated. He agreed with Dr. Rayner's remarks concerning the rating of electrical plant. He had not given much attention to the question of heating tests in his paper as this was a comparatively simple matter, but in any case he considered that the criterion of heating alone was an unfortunate one to adopt, and militated considerably against progress in the design of machines. From one point of view it would appear that the specification of heating limits should tend to improve the efficiency of machines, as the higher the efficiency the smaller the amount of heat to be wasted, so that if a machine had perfect efficiency there should be no need for a large cooling surface, and therefore a large and heavy machine. Unfortunately, other considerations in design did not fit in with this, and he thought that specifications of the efficiency and regulation of machines should be issued, and that the old rivalry for the production of the most efficient type of machine should be revived. In this connection he was interested in Mr. Sayer's remarks concerning his new type of dynamo with greatly reduced losses, which was a great step in the right direction, and Mr. Sayers had clearly appreciated his contention that for improvement in the design of machines it must be possible to make an accurate experimental analysis of the various losses. It was with this object that the devices he had described in his paper had been brought out, but he was sorry to notice that the majority of the speakers appeared to consider that the testing equipment of the kind he had mentioned would be costly. On the contrary, although the methods were certainly susceptible of high accuracy, special consideration had been given, as mentioned at the outset of the paper, towards reducing the complexity of the apparatus in order to obtain efficient testing plant with the minimum expense, and he was sure that if makers would go into the question they would find that a material saving would be made on their ordinary testing cost, with great gain in accuracy, by the adoption of the methods described.

NOTE ON WATERPROOFING CONCRETE.

By H. Singh Bonsor, A.S.E.

Up to the present time various methods have been proposed to render concrete waterproof. If mixed fairly wet, when it is laid, it will be more waterproof than if mixed quite dry. Sometimes a coat of pure cement ½ in. thick is applied after the work has set. Of course, the concrete may be painted with waterproof paint, but this is often unsightly. A material which is better than paint although unsightly, is asphalt. The concrete must be dry before the asphalt is applied. The asphalt is applied while boiling hot, and is put on with a brush.

Another method of making concrete waterproof is by using the Sylvester process. After the cement, sand and broken concrete to gauge are mixed, alum is added to the mass in the proportion of 20 lbs. of alum to 27 cu. ft. of concrete. The water that is added to make the concrete, has in it *Castile soap* in the proportion of ¾ lb. of soap to 1 gallon of water. The alum and soap form an insoluble, gelatinous substance that fills all the pores of the mass. It is not necessary, however, to resort to any waterproofing process for concrete. If the materials are mixed fairly wet and well tamped, they will usually be impervious to water with no additional precautions.

In cases where walls are found to be affected by damp on account of the capillary attraction of water to a height of 32 ft. or due to other causes ; the best remedy is to apply the following solution, which gives reliable results. Take ¾ lb. mottled soap to a gallon of water, to be applied boiling over the surface with a brush, leave it for 24 hours to dry ; then apply ½ lb. of alum to 4 gallons of water, this is left for 12 hours to dissolve. Hot weather is most suitable for the application.

To enjoy a healthy life—dampness in houses should be prevented altogether by applying one or other solution as given above, no doubt dampness in houses is a contributory cause of several diseases such as malaria, rheumatism, dysentery, and tuberculosis. This can be justified by the statement given by one eminent medical man, the late Surgeon General Sir Pardey Lukis, K.C.S.I., V.D., in his book *Tropical Hygiene.* He states that the germs of tuberculosis take birth in dampness, while in dry air the reverse is true.

THE SOCIETY OF ENGINEERS (INCORPORATED).

INCOME AND EXPENDITURE ACCOUNT, FOR THE YEAR ENDED 31ST DECEMBER, 1921.

Year ending *31st Dec.*, 1920. £	s.	d.	EXPENDITURE.	£	s.	d.	£	s.	d.
296	15	4	To Printing Transactions ...	310	8	1			
37	5	11	*Less* Sales & Advertisements	48	10	11			
259	9	5					261	17	2
			Administration Expenses—						
300	0	0	Salary of Secretary	300	0	0			
			Bonus to Secretary	50	0	0			
93	10	0	Rent of Offices	102	0	0			
19	2	4	Fuel, Lighting & Office Cleaning	22	6	1			
82	18	2	Postage, Telegrams, Carriage and General Expenses ...	92	17	8			
65	9	10	Stationery & General Printing	54	0	3			
	—		Printing List of Members ...	50	4	0			
32	15	5	Audit Fee and Law Charges ...	22	6	0			
593	15	9					693	14	0
			,, *Meeting Expenses*—						
9	14	6	Hire of Rooms	7	7	0			
1	1	0	,, Lanterns	1	1	0			
14	9	3	Reporting Meetings		—				
19	11	11	Refreshments for Members at Ordinary Meetings, etc. ...	14	3	7			
44	16	8					22	11	7
0	17	2	,, Depreciation of Office Furniture					—	
1	18	6	,, Library ...				1	14	8
3	0	8	,, Interest on Benevolent Fund				3	3	1
	—		,, Income Tax on Bank Interest				0	18	0
			,, Premiums presented by the Society				3	3	0
5	5	0	,, "Geen Premium" *Per Contra*				5	5	0
			,, Balance, being Excess of Income over Expenditure, carried to Accumulated Fund Account				154	11	6
£909	3	2					£1,146	18	0

Year ending *31st Dec.*, 1920. £	s.	d.	INCOME.	£	s.	d.	£	s.	d.
751	17	3	By Subscriptions				999	10	11
88	14	6	,, Admission Fees				117	1	6
3	9	4	,, Interest on Deposit				2	6	7
			,, *Interest on Investments*—						
12	14	6	London & North Western Rly. 3 per cent. Debenture Stock	12	14	6			
7	7	0	India 3½ per cent. Stock ...	7	7	0			
20	1	6					20	1	6
6	8	2	,, Sundry Receipts				2	12	6
5	5	0	,, Donation from Mr. Burnard Geen, Past President, for "Geen Premium"				5	5	0
10	0	0	,, Special Donation					—	
1	6	6	,, Premiums					—	
22	0	11	,, Balance being Excess of Expenditure over Income, carried to Accumulated Fund Account					—	
£909	3	2					£1,146	18	0

THE SOCIETY OF ENGINEERS (INCORPORATED).

BALANCE SHEET, 31st December, 1921.

Year ending 31st *Dec.*, 1920. £	s.	d.	LIABILITIES.	£	s.	d.	£	s.	d.
227	13	7	*Sundry Creditors*	142	3	3			
—			Donation from Mr. Wm. Clarke for Clarke Premium not awarded	10	10	0			
							152	13	3
95	17	2	*Subscriptions in Advance* ...				46	5	0
			Life Membership Account—						
89	10	8	As per last Balance Sheet ...	86	2	2			
3	8	6	*Less* 5 per cent. Transferred to Income on account of Life Subscription expired ...	4	6	2			
86	2	2					81	16	0
			Benevolent Fund Account—						
75	17	0	As per last Balance Sheet ...	78	17	8			
3	0	8	*Add* Interest at 4 per cent.	3	3	1			
78	17	8					82	0	9
277	0	5	*Accumulated Fund Account*, being Excess of Assets over Liabilities as per last Balance Sheet ...	196	19	6			
22	0	11	*Add* Balance from Income & Expenditure Account ...	154	11	6			
254	19	6		351	11	0			

Year ending 31st *Dec.*, 1920. £	s.	d.	ASSETS.	£	s.	d.	£	s.	d.
			Cash—						
72	7	3	At Bank, Current Account ...	94	2	3			
57	3	1	,, Deposit Account ...	59	9	8			
6	9	6	In hands of Secretary	9	16	10			
135	19	10					163	8	9
			Sundry Debtors—						
23	2	0	Subscriptions in arrear and received up to 20th January, 1922	24	13	6			
2	18	0	Advertisements in Journal, etc.	2	15	0			
1	6	0	Owing on account of Premiums	5	5	0			
27	6	0					32	13	6
			Investments.						
524	19	0	£606 London & N.W. Rly. 3 per cent. Perp. Deb. Stock at 86½ as per last Balance Sheet ...	524	19	0			
278	13	6	£300 India 3½ per cent. Bonds at cost as per last Balance Sheet	278	13	6			
803	12	6		803	12	6			
338	0	0	*Less* Reserve for Depreciation (The Market Value of these securities at 31st December, 1921, was £517 18s. 5d.) ...	286	0	0			
465	12	6					517	12	6

58 0 0	*Add* Amount deducted from Reserve for Depreciation of Securities to reduce total Reserve to £286 ...	52 0 0	
196 19 6			403 11 0
£685 10 1			£766 6 0

	Office Furniture—		
17 2 8	As per last Balance Sheet ...	16 5 6	
0 17 2	*Less* Furniture Sold	2 3 6	
16 5 6			14 2 0
	Library—		
19 5 2	As per last Balance Sheet ...	17 6 8	
1 18 6	*Less* Depreciation at 10 per cent.	1 14 8	
17 6 8			15 12 0
	Stocks on hand—		
22 10 0	Transactions and Journals ...	22 0 0	
0 9 7	"Law Relating to Engineering"	0 17 3	
22 19 7			22 17 3
£685 10 1			£766 6 0

THE SOCIETY OF ENGINEERS (INCORPORATED).

BALANCE SHEET, 31st DECEMBER. 1921.

THE BESSEMER PRIZE FUND.

Year ending 31*st Dec.*, 1920. £ s. d.	EXPENDITURE.	£ s. d.	£ s. d.	Year ending 31*st Dec.*, 1920. £ s. d.		£ s. d.
102 11 2	As per last Balance Sheet ...	96 5 7				
5 11 0	*Add* Appreciation in value of Investment	11 2 0		90 13 0	£185 N.E. Rly. 3 per cent. Debenture Stock (at Market Value 31st Dec., 1921)	101 15 0
97 0 2		107 7 7		5 12 7	Cash in hand	9 10 3
3 17 8	*Add* Income from N.E. Rly. Debenture Stock	3 17 8				
100 17 10		111 5 3				
4 12 3	*Deduct* Cost of Premium ...	—				
			111 5 3			
£96 5 7			£111 5 3	£96 5 7		£111 5 3

THE NURSEY PRIZE FUND.

£ s. d.		£ s. d.	£ s. d.	£ s. d.		£ s. d.
32 10 2	As per last Balance Sheet ...	31 9 6				
2 6 2	*Add* Income from Hammersmith and City Rly. Ordinary Stock	1 5 6		27 7 10	£33 Hammersmith & City Rly. Consolidated Ordinary Stock (at latest available quotation to 31st Dec., 1921)	27 7 10
30 4 0		32 15 0		4 1 8	Cash in Hand	2 4 2
1 5 6	*Deduct* Cost of Premium ...	3 3 0				
			29 12 0			
£31 9 6			£29 12 0	£31 9 6		£29 12 0

THE BERNAYS PRIZE FUND.

£ s. d.		£ s. d.	£ s. d.	£ s. d.		£ s. d.	£ s. d.
16 16 7	As per last Balance Sheet ...	17 9 6		14 11 2	£13 N.& S.W. Junction Rly.Stock (at latest available quotation to 31st Dec., 1921)		14 11 2
0 12 11	*Add* Income from N. & S.W. Junction Railway Stock ...	0 12 11		2 18 4	Cash in hand on Capital Account	2 3 9	
			18 2 5		,, ,, Income Account	1 7 6	3 11 3
£17 9 6			£18 2 5	£17 9 6			£18 2 5

We have prepared the above Balance Sheet and Income and Expenditure Account from the Books and Vouchers of the Society, and have obtained all the information and explanations we have required. In our opinion the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Society's affairs according to the best of our information and the explanations given us, and as shewn by the books of the Society.

3, Raymond Buildings,
Gray's Inn, London, W.C. 1.
26th January, 1922.

(Signed) BEGBIE, ROBINSON, COX & KNIGHT,
Chartered Accountants.

Monday, April 3, 1922.

T. J. Gueritte, B.Sc.(Paris), M.Soc.Ing.Civ.(France), F.S.E.,
President, in the Chair.

FRACTURES IN CONCRETE.

By Harry Bentham.

In connection with various works of public importance new and old problems generally present themselves for investigation and solution and are worthy of careful consideration.

The author carried out works for a Borough Council in the south-west of London from April to September, 1920, to a thoroughfare that had to be re-constructed to satisfactorily sustain the present day fast and heavy traffic, including a constant motor 'bus service, and the experience here recorded may prove interesting.

The works were of a very ordinary character, being the excavation of the existing metal carriageway and reinstatement with a 9 in. concrete bed without reinforcement, the concrete being brought to a medium face with the shovel, and left fit to receive a 2 in. coat of compressed mineral rock asphalte, the latter being laid by a well-known London asphalte company.

The thoroughfare is an old one, well drained, and the subsoil gravel and sand.

The cement was of English manufacture, and complied with the British Standard Specification. No cement was used unless it had laid on the site for two weeks, and 14 days' supply for the work was kept in hand. Each consignment of cement of not less than 20 tons was tested, and only on passing such test was it allowed to be used.

The aggregate was Thames ballast, clean and sharp, and no stone was larger than 2 in. gauge.

The proportion of sand to ballast was not definitely specified, so that the aggregate under these conditions varied.

If any excess of sand was delivered in the ballast it was rectified by a sufficient addition of clean screened pit ballast.

Gauging : 6 of Thames ballast and sand to 1 of cement.

In mixing, the aggregate was turned three times dry and three times wet.

The concrete was left for 12 days before the compressed asphalte was laid.

The sequence of operations was : Excavation of the existing macadam, formation of the foundation, dumping of the aggregate in the centre of the carriageway, concreting and laying the final face of 2 in. of compressed mineral rock asphalte.

No screed beds were used, pegs being sighted in to the required levels as the work progressed.

It may be of interest to mention that in carrying out the excavation of the existing macadam an American machine named the " Snorter " was tried for scarifying the foundations. It had a base of about 90 sq. ft. and a boom 30 ft. long by 6 ft. wide, with 4 to 6 tines adjustable to various depths of cut. In starting it to work a trench 2 ft. wide was excavated across the carriageway to a depth of 6 in. The " Snorter " was backed to the face of the macadam, and a cut of 4 in. depth was first taken and proved effective in " lifting " a width of 4 ft. 6 in. at one time, until it met a hard face, where it was thrown out of the plane, and failed to recut its way into the work. The tractive power used was a 10 ton steam roller. This machine, after several attempts to work it, proved a failure and was abandoned, the remainder of the work being done with a Morrison scarifier.

Mixing of Concrete.

The concrete was machine mixed throughout the work, with the exception of about 30 cubic yards. An American self-propelled hopper concrete mixer was used, the capacity being ½ a cubic yard, the discharge from the drum being into a bucket running on a boom capable of delivery at a 15 ft. radius. The water supply for each gauging was registered and automatic. From 60 to 80 cubic yards per day (of 8½ hours) was the general output, the time taken for filling into hopper, mixing, discharging and levelling taking between 3 and 4 mins. per batch. The distance covered per foot of carriageway varied from 50 to 60 ft. per day, and the area from 240 to 320 square yards.

The line of route throughout was kerbed with 12 in. by 8 in. granite, the footways were laid with mastic asphalts on a 4 in. concrete foundation.

During the execution of the work the whole of the carriageway was closed to traffic, thus enabling the full width of roadway to be covered in one operation, and obviating any longitudinal junction.

At the conclusion of each day's work the finish was left as near a right angle to the kerb as possible, the ends being stepped for bonding in on to the next day's work.

A section of concrete roadway 802 ft. long, having an area of nearly 3,000 square yards, was completed when, about 7 to 10 days afterwards, the author noticed a faint line in one or two cases taking a transverse course across the concrete. These cracks were so fine that they could not be followed the whole width of the road, but were clearly visible at, and commencing from, the kerb line. They were carefully watched, and were found to develop so that they could be definitely traced the entire width of the carriageway, the course being irregular, but in all cases they extended the full width of the road from kerb to kerb. As the setting of the concrete proceeded, the cracks slowly developed in width, so that they could be clearly defined as fractures measuring from $\frac{1}{64}$ to $\frac{1}{32}$ of an inch in width, and in wet weather and early in the morning they were most prominent, the greatest width of the fracture being at the kerb side.

Investigation was carefully made by cutting each side of the line of fracture to see how far it penetrated the concrete, and no trace could be seen beyond a depth of 1 in.

The weather during the time was normal summer weather, the temperature averaging 66°.

The work was continued upon the same line as described, and further areas were covered.

These fractures were not considered sufficiently serious to interfere with the laying of the compressed asphalte, so after 17 days from the placing of the concrete the 2 in. compressed asphalte was laid over an area of 1,300 square yards, and the section was opened to traffic the following day, *i.e.*, within 21 days from the commencement of concreting.

Within 7 days from the completion of the first section of asphalte work and the throwing open of the same to traffic, a fracture appeared through the asphalte on one side of the road and slowly developed, following the lines of the defective concrete, until finally the line was completed across the whole width of the carriageway. Again it was noticed the most prominent place of fracture was at the kerb sides of the road. This crack did not open to the same extent on the face of the asphalte as that in the concrete had done.

At the expiration of 10 days, as the line had not wheeled out, a section 3 ft. by 1 ft. was cut out of the asphalte, and on inspection of the concrete there appeared to be no widening of the fracture or other defect in the concrete foundation. The compressed asphalte was then made good, but in the course of a week the line of fracture reappeared in the face of the asphalte and has remained there.

Further concrete foundations were made on the same lines as described. It was then noticed that these cracks commenced to develop within 7 days from the laying of the various sections of concrete, and, with great regularity, they followed the course at right angles to the kerb, and in no case was the line intermittent or failed to traverse the whole width of the carriageway. It was also noted that the defects occurred at a distance of 2 ft. to 6 ft. either in advance of or in arrear of the line marking the finish of the previously completed sections. A section of the concrete was carefully cut out across the carriageway to a depth of about 3 in., where a fracture had stood for some time, and this was made up with cement and sand 3—1, but again the same line of cleavage appeared in about 14 days.

On one section of the work an entrance had to be continually given to some business premises. It was decided this should be done well in advance of the work in progress, and when ready for concreting the mixer was moved down, and a length of 150 ft., with an average width of 47 ft., was executed in two longitudinal sections, a period of 21 days elapsing between the laying of one side of the road and the final completion. Where this method was carried out no transverse or longitudinal fractures occurred.

As the asphalte work followed on to completion, wherever a fracture occurred in the concrete base, so, sooner or later, the line was disclosed in the face of the asphalte.

A piece of concrete with a surface fracture running through the centre, an area of 2 sq. ft. was carefully cut out of the foundations. From this an 8 in. cube was subsequently taken, and the result of a compressive test was 1,050 lb. per sq. in., equal to 67·5 tons per sq. ft.

The laying of the concrete foundations commenced on May 10, and continued, with slight intermission, for a period of 9 weeks, when it was practically completed.

The following schedule gives data that will be interesting, and the author calls attention to a section laid between May 18 and 29, being a length of about 450 ft., in which only one fracture of any import occurred. This portion was the flattest area on the line of route.

The defects which appeared in the asphalte were clearly due to the foundations. Compressed asphalte being a natural mineral rock containing about 10% of bitumen is reduced to powder by being beaten in a machine to such a fineness that 40% to 50% passed a 100-mesh screen, 15% a 200-mesh screen, and the residue a 50-mesh screen. The powder is heated to the required temperature in revolving cylinders, and while hot is taken to the site and laid in the powder form, nothing being added to the material. It is then levelled, punned and consolidated with heated irons, and within 24 hours is fit to take the traffic.

The asphalte when laid has a restricted elasticity. The tyres of vehicular traffic on new work frequently cut into the face, but the succeeding traffic, sooner or later, rolls this out, leaving an extremely hard and durable surface.

One remedy tried was to cut out the fractures appearing in the asphalte to a depth and width of 2 in. into the concrete, and make good by filling the whole cut with compressed asphalte.

Dates Concrete was laid.	Maximum Screen Temp. ° F.	Distance from Base Ft.	Date of appearance of fractures in concrete.	Date the compressed Asphalte was laid.	Date Fractures appeared through face of Asphalte.
1920.					
May 10 ...	61				
,, 11 ...	65				
,, 12 ...	70		May 17		June 10
,, 13 ...	63	186			
,, 14 ...	65		,, 22		
,, 15 ...	62				
,, 17 ...	60		,, 25		
,, 18 ...	62	381		May 29	,, 14
,, 19 ...	61				
,, 20 ...	62		,, 28		
,, 21 ...	65				
,, 22 ...	70		,, 28		
,, 26 ...	71				
,, 27 ...	69				
,, 28 ...	73				
,, 29 ...	70	837		June 11	,, 16
,, 31 ...	63				
June 1 ...	72		June 7	,, 28	
,, 2 ...	75				
,, 3 ...	70				
,, 4 ...	57				
,, 5 ...	57	1,167	,, 12		
,, 7 ...	61				
,, 8 ...	61				
,, 9 ...	62				
,, 10 ...	59				
,, 11 ...	66				
,, 12 ...	73	1,474	,, 17		
,, 14 ...	71				
,, 15 ...	72				
,, 16 ...	75				
,, 17 ...	76				
,, 18 ...	73				
,, 19 ...	70	1,814	,, 23	July 2	
,, 21 ...	69				
,, 22 ...	72				
,, 23 ...	73				
,, 24 ...	72				
,, 25 ...	70				
,, 26 ...	67	2,115	July 2	,, 24	
,, 28 ...					
July 1 ...	63				
,, 2 ...	66				
,, 3 ...	67		,, 12		
,, 5 ...	52				
,, 6 ...	64				
,, 7 ...	62				
,, 8 ...	61				
,, 9 ...	66				
,, 10 ...	62				
Aug. 10 ...		2,555		Aug. 21	

This did not prove effective, the fractures reappearing through the asphalte in 14 days, and gradually opening and extending throughout the whole width of the carriageway.

The work was completed in September, 1920, and other than the flaws mentioned herein, the surface was in excellent condition.

On a recent inspection 12 months after the completion of the work and close examination of the fractures through the asphalte, the lines adjoining the kerbs were most apparent, but in places in the centre of the carriageway it is now difficult to trace.

At points near the kerb line where the fractures were very distinct the traffic appeared to have made a slightly concave impression upon the face of the asphalte extending a distance of 6 in. on each side of the line.

Whether this will develop to any further appreciable extent and tend to the rolling of the surface and corrugations remains to be seen.

In addition to the original fractures that were known to exist before the work was asphalted there now appears in several instances lines of cleavage through the asphalte all of which take a transverse course, but are not in any way so serious, distinct, or complete as the former ones, clearly tending to prove that the causes of fractures were from one direction.

It is well known that in laying '*in situ*' concrete paving to prevent fractures therein, provision is made for the insertion of $\frac{1}{4}$ in. to $\frac{3}{4}$ in. fir as an expansion joint.

Attention should be drawn to the fact that the site of the road was between two lines of railway, which ran parallel to each other and to the road, at a distance of about 250 feet on the North side, and of about 450 feet on the South side, each railway constructed on embankment, with another overhead railway line crossing the road at the West end. This is mentioned as it had been suggested that the fractures were due to vibration.

For some distance on the line of route a brook had existed, but this had been covered in for some years.

In carrying out the work every care was taken to ensure its being executed strictly to the requirements of the specification, in regard to the aggregate, cement, mixing and placing of the concrete.

The author ventures to suggest that the fractures are due to :—

(a) the expansion and contraction in the bulk.

(b) the action and re-action caused by the setting of the concrete.

(c) The contour formation of the concrete bed tending to any excess of water finding its way to the kerb lines each side of the road, with the consequent retardation of the setting at that point.

(d) the omission of any provision to take up the expansion on the longitudinal line.

Generally the longitudinal gradient was uniform varying from 1 in 300 to 1 in 75, the latter being for a very short length.

Since the work was completed a similar contract has been executed in another district, the finish of the surface being 2 in. compressed asphalte laid by the same company. The specification was, however, different, the aggregate being 6 Thames ballast to 1 of cement, mixed by a concrete machine, the total depth of foundation being 2 in. concrete re-inforced with No. 9 gauge steel fabric to the British Standard Specification, and covered with a further 6 in. of concrete, the whole left with a shovel face finish.

The laying of the asphalte in this case proceeded within 7 days of the laying of the concrete, and during this period no sign of fractures was evident, nor has there been any sign of such through the asphalte, the work being in an excellent condition.

The author in 1914, in the North West of London, carried out about 30,000 square yards of similar concrete foundations having a thickness of 9 in. with a 3 in. bed of 2 in. granite macadam between the clay subsoil and the base of the concrete.

The aggregate was Thames ballast and sand 5 parts to 1 cement, turned twice dry and three times wet. Screed beds were used in bays of 15 to 16 ft. widths, and the concrete faced for wood paving.

The concrete in this case was hand mixed and no trouble occurred in regard to fractures in the concrete, though in some cases there were traces of fracture, but of no serious portent.

In October, 1920, a thoroughfare was opened and re-constructed in the West of London, the subsoil being sand and ballast thoroughly consolidated.

Concrete foundations were put in to a depth of 12 in., no re-inforcement being used. The concrete was composed of 6 Thames ballast to 1 of cement, the mixing being by hand and turned five times, twice in a dry state, once in watering, and twice wet.

At the time of completion some slight fractures were disclosed, but these were not considered of any serious account. Evidence of their increase was given about 15 months afterwards in the fractures appearing through the face of the asphalte.

Within the last 2 years in the South East of London an important thoroughfare was re-constructed and a depth of 10 in. of concrete laid as a foundation with steel fabric as reinforcement.

Here, before the surface was covered, some evidence of minor fractures were noted before the asphalte was laid, and since its completion these have been disclosed through the face of the asphalte, but to a minor extent.

In 1890, the author carried out the re-construction in the South East of London, of a main road thoroughfare with a single line of tramway running through the whole route, which was subject to a very heavy traffic and a constant horse-bus service. The subsoil was ballast and sand free from water.

The depth of concrete laid was 6 in., the surface being paved with 3 in. and 5 in. Aberdeen granite setts. The aggregate used was clean Thames ballast as dredged.

The concrete was mixed 3 times dry and 3 times wet and put in by hand labour, pegs being boned in for height and no screed beds used. The gauging was 11 of ballast to 1 of concrete.

No sign of fractures occurred in the work, and as an instance of its stability may be mentioned the fact that 2 years after the completion of the work a subsidence occurred in the roadway and investigation showed a settlement of the subsoil for several feet in depth over an area of about 64 square feet, owing to the existence of an undiscovered well. The 6 in. bed of concrete had carried the whole of the traffic with safety for a considerable period.

The elimination of the possibility of these defects appearing in concrete surfaces would be a great achievement as, owing to urgency in construction, engineers often find themselves compelled to give as short a time as possible to the aeration of concrete surfaces. The present period is one in which increasing areas throughout the country are being laid down in concrete, in addition to which we have a new material, rubber, promising to come to the front for paving, and here again concrete will be used as the foundation.

It is to be regretted that a series of photographs was not taken from time to time shewing the developments of these defects both through the concrete and asphalte in the works first mentioned.

The author has endeavoured to present the facts in regard to the work and trusts that they will lead to an interesting and profitable discussion on the subject. The present day cost of engineering work emphasises the great importance of all completed work being free from any present, or future defects.

Discussion.

Mr. A. S. Buckle, M.Inst.C.E., thought that cracks were generally due to contraction of the concrete at the time of what might be called the final set, viz., when it was about three months old. He had had no experience in concrete roads, but he had in retaining walls, and in these his practice had been to put in a sheet of ruberoid about every 120 feet with excellent results.

He thought it a mistake to speak of expansion joints. No one ever saw a concrete road buckling up, it was contraction not expansion that had to be dealt with.

Roads, he believed, were sometimes made in sections not contiguous to each other, so as to eliminate the contraction, the intervening spaces being filled in after some of the contraction had already taken place. This appeared to have been done in one case with good results.

In this connection he might mention that he had seen some very bad work going in in London streets as a foundation for wood block paving. Dirty ballast mixed dry with dirty sand, then the cement and water are added together, and after once turning over it goes into the work. Work entirely left to the workmen who put in as much water as they pleased.

He referred to the use of shutes for pouring concrete into reinforced concrete buildings, and thought that it produced bad concrete liable to crack owing to the excessive amount of water required to make the concrete run in the shutes.

He asked the author to explain why asphalte was used at all, instead of constructing a purely concrete road. One such, he believed, had been made during the war which carried all the traffic to Southampton Docks with great success. There were also many thousands of miles of concrete roads in the U.S.A. He had had some experience of making concrete blocks. There one had to make it nearly dry, in order that the block might be carried off at once, and it was surprising what little water was really required.

He thought that engineers in the past had allowed the workmen to use too much water, which they always did if they could, in order to make it run better.

Mr. C. H. J. Clayton, M.Inst.C.E., complimented the author upon the interesting paper he had presented, but thought that it lacked completeness owing to the omission of any reference to the water content of the concrete used. He agreed with the last speaker that workmen commonly used far too much water in mixing, perhaps because it was easier than semi-dry mixing and handling, but he was convinced that expansion and contraction in structures of mass concrete was less to be feared where the water used in mixing had been kept down to a minimum. Recent experiments in the United States had shown also that the drier the mixture the greater the strength on maturity.

He was unable to suggest to himself a satisfactory reason for the phenomenon that the cracks referred to by the author were wider near the kerbs than in the other parts of the width of the road, but thought that that was not wholly unconnected with the fact that excess water from the mass would drain that way. As to the general direction of the cracks there was no question that as expansion was prevented from taking a lateral direction by the resistance of the kerbs, it could only take place longitudinally, and that any cracks due to expansion would then occur in the direction of the width.

A. S. Grunspan, B.Sc., A.C.G.I., A.M.I.C.E., congratulated the author upon the interesting paper submitted for discussion, and said the subject was of extreme importance which has to be viewed from a different aspect from the one customary hitherto. We were now dealing with modern conditions of traffic, and the roads have to be made strong enough to carry efficaciously heavy loads at fast speeds.

He asked the author whether he had made any observations in regard to the cracks, which were so pronounced at the kerb, at varying distances from the kerb line, that was to say, for what distance from the kerb was the crack pronounced, and at what rate did it diminish. He thought this was important in order to form some sort of an explanatory theory why the crack was more pronounced near the kerb.

He also wished to know how many cracks occurred in the 802 feet length. Was he right in assuming that two cracks only occurred in this length ? If so, they appeared to be about 300-400 feet apart, which must be accounted for by expansion. They all knew that in elevated reinforced concrete structures an expansion joint should be put every 300-400 feet, and it was equally if not more important to provide expansion joints in concrete roads.

The author pointed to a case where a road reinforced with No. 9 B.R.C. fabric placed 2 inches from the bottom was immune from cracks. He could not see how the reinforcement, when placed at the bottom, could have stopped the cracking of the road. For the purpose of eliminating cracks, the road should be reinforced at the top rather than at the bottom, for if the subsoil were good there was no need for reinforcement, and in any case the amount of reinforcement put in the road would not be sufficient to take tensile stresses induced in the concrete, owing to defective subsoils. The reinforcement, therefore, should always be placed at the top of the road rather than at the bottom.

Mr. Bentham gave some figures relating to the crushing strength of the concrete used, and quoted 1,050 lb. per square inch, at the age of 28 days. This indicated to him a poor concrete, for if the aggregate were well chosen and properly graded, with a 1 : 2 : 4 mixture, a concrete should be produced which should stand from 2,400-3,000 lb. per square inch. The speaker rejected concrete which was not capable of standing 3,000 lb. per square inch at the age of 28 days, when made of a mixture in the proportion of 1 : 2 : 4.

The previous speakers raised the question of transmitting concrete by means of chutes, as they were doing in America, and asked whether there was any objection to such practice. The best results cannot be obtained by that method, because all the care taken in grading the concrete was destroyed. The chute principle was essentially a gravity principle, and by " pouring " the concrete the larger particles fell first and the smaller followed, and thus the carefully graded concrete was ungraded. As regards the amount of water used in the mixing of concrete, it was better to have a too dry concrete rather than too wet, because when concrete is too dry the deficiency shows itself straight away ; with an overwet concrete, the defects do not manifest themselves until the concrete had set and was subjected to tests. The amount of water used in the mixing of concrete should be such as to make it just rise to the surface when the concrete was well tamped. A doughy consistency should be aimed at, and sloppy mixtures should not be allowed.

The cracks to which the author had drawn attention point to the advisability of precasting the concrete road and putting it down in sections. He had recently designed such a road, which had been put down at Southall for the G.W. Railway Co., and appeared to be successful. The chief trouble of roads built *in situ* was that the road had to be closed to traffic for some considerable time to give it a chance to mature ; this unfortunately, was never done sufficiently because of the delay it involved, and the nuisance created by closing the road for too long a period. Furthermore, the concrete road built *in situ* must crack, no matter what precautionary measures were taken. When once a crack was established, a slight difference in level was formed between the bays of concrete separated by the crack, and was further aggravated by a wheel having to " jump " from the higher to the lower level, creating impact. Were it not for the impact, the crack would not be of any importance and could be easily neglected. The impact, however, greatly aggravated the situation and played havoc with the roads. These things the road engineer had to bear in mind when dealing with modern conditions of traffic.

Mr. W. H. Woodcock emphasised the point raised by previous speakers that excess of water in gauging should be avoided where a good solid concrete, free from shrinkage cracks, was required. On the other hand there must be sufficient water present to ensure the complete reaction which takes place when cement sets. If the concrete were gauged with just enough water to enable it to work properly, there would be sufficient to enable all the cement to set.

As a further illustration of careless mixing, mentioned by a previous speaker, he had, on several occasions, for examination pieces of concrete which had given way under wooden blocks, while the surrounding concrete was sound and hard. In nearly every case it was found to be due to faulty mixing, some of the aggregate being practically free from cement, whilst other portions contained an excess, and in some cases the sand had separated from the gravel. As in most of these cases the materials were similar to that of the surrounding good concrete, the failure was not due to the materials, but to the mixing.

The author, towards the end of his paper, stated that, owing to urgency of construction, engineers often found themselves compelled to give as short a time as possible to the aëration of concrete surfaces. The author probably meant "maturing," instead of "aëration," as concrete will harden satisfactorily without aëration. The question of quick maturing was of importance to engineers for concrete work which had to be used soon after it was put in. Some types of Portland cement required several days to harden or mature, but many of the finest grades of cement matured so rapidly that in three days they would, when neat, stand a tensile strees of nearly 500 lb. per square inch.

Where such cement was required, he suggested that tensile tests for 24 hours and 3 days be made, in addition to those in the British Standard Specification.

As there was an appreciable demand for quick maturing cement for various purposes, many experiments had been made to prepare such a cement. There was at present on the market at least one such cement which developed over 500 lb. per square inch in one day, and 900 lb. in three days, although it was not a true Portland cement in composition. This cement was too costly for general use, but development along these lines might be looked for, with a consequent reduction in price.

Mr. Hal Gutteridge, A.M.I.M.E., M.Tech. Insp. Assn., said the subject of "fractures in concrete," raised by the author, was one of great importance, not only to the concrete engineer, but to all engineers. So comparatively little was known about the laws governing the initial setting of concrete, and the relation between the moisture content, the percentage of voids, the grading of the sand and aggregate, the mixing, the curing, to the strength, durability and imperviousness of concrete, that any addition of experience in concrete work is valuable.

It was remarked that the compressive strength of the concrete in the case the author discussed, was, at about three weeks of age, 1,050 lb. per square inch. This strength was low, as for a mixture of 4 : 2 : 1 at the same age frequently gave values of 3,500 lb. per square inch. It would have been interesting to have had compression strengths of the concrete at later ages, as it was possible that the strength of this particular concrete might have increased at a slower rate, and eventually reached a high figure, which, in the speaker's opinion, was, within limits, no disadvantage, but preferable to a quick gaining of strength which frequently was at the expense of the strength at later stages.

As concrete, in initial setting, contracts about ½ inch in every 100 feet, depending on local and other conditions, which in this case appeared to be aggravated by the presence of moisture in the sub-soil, and of heat from a mid-summer sun, it was suggested that some relief from the fracturing might have been secured by " curing " the concrete in keeping damp soil or other material on the top of the road till the asphalte was applied, or by laying the concrete in alternative bays, so that the initial contraction of these bays could have taken place without restraint, before returning to fill the intervening spaces. In this case the tension at the surface of the concrete, due to initial contraction, was, undoubtedly increased by its being " anchored " to the preceding bay, and thereby not free to contract, causing fractures to take place owing to the ultimate tensile strength of the concrete being exceeded. There was also another recognised method of obviating high tensile stresses by the provision of expansion joints, which in various forms, were frequently used in practice for this purpose.

Mr. Buckle, in his remarks, referred to the Southampton concrete road which, without any top dressing, had stood up to the traffic conditions with every satisfaction, and the speaker could refer to another good example of a similar concrete road without any top dressing, at Forgate Street, Chester, which road, carrying an estimated traffic of 2,000 tons daily, after 12 months' service was reported to be in excellent condition.

Mr. F. C. Evennett said it was hardly surprising to learn that concrete was subject to dimensional change during its initial process of setting and hardening, or subsequently during temperature variations. That this change was manifested by unpleasant cracking in a structure or road when this material was used, emphasised the need for investigation, with a view to lay it in such a fashion that its rupture would be as small as possible, and to provide suitable jointing where rupture could not be avoided.

Concrete was known to contract on hardening, from ·02 to ·05 per cent., varying with the mixture and the authority. It was also known to expand or contract with temperature change, its co-efficient of expansion being somewhere about ·000006 per °F., so that it was extremely unlikely that a concrete road would ever be satisfactorily laid without some provision for those movements.

In this particular case it seemed probable that the cracks were caused by (*a*) the shrinkage of the concrete on hardening, (*b*) by more rapid drying or hardening at and near the surface than below, and (*c*) by surface cooling during the night.

The shrinkage (*a*) would place the whole bed in tension, and the other two factors would increase that tension at the surface, where the cracks apparently did commence.

He noted that the author had had pleasant experience by covering the concrete early, and it was interesting to learn that the New York Board of Water Supply included in their specifications the condition that " Concrete shall be kept moist for at least two weeks after the removal of the forms, or until covered with earth, unless otherwise directed."

It was likely that earlier covering would solve part of the problem.

Some bare concrete roads he had had under observation in the State of Pennsylvania, U.S.A., were laid in sections of about 15 to 20 feet in length, and across the whole width of the road, the surface being without camber and the sections separated by $\frac{3}{8}$ inch soft-wood boarding. They stood up well, and with very little cracking, but when once the surface was damaged, disintegration proceeded rapidly .

He thought it probable that by early covering, and by placing an expansion joint, say, at 40 or 50 yards intervals, much economy in road maintenance could be effected.

Mr. E. W. Palmer said he was interested in the road to which the author referred in the first part of his paper, and the reason he had deferred his remarks was because his firm had been consulted professionally regarding the cracks in the road referred to at pp. 1 to 6 of Mr. Bentham's paper. In conjunction with one of his colleagues he had inspected the road in question, and could confirm all the details given by the author respecting the cracks which had occurred at more or less regular intervals. It was well known that in all horizontal surfaces built of unreinforced concrete, especially if exposed to atmospheric conditions, cracks occur unless the concrete was built in sections, and it was usual to put a parting between each section and then after the concrete had set to fill in with concrete, slurry, or asphalt. In the opinion of his firm the reason why the cracks occurred approximately in the same position in the road referred to by Mr. Bentham was that the new concrete was anchored at one end by attachment to the concrete already set and the new concrete contracted, being held at one end and free at the other, the crack occurred near the bond.

With reference to the remarks made by Mr. Woodcock, respecting the hardening properties of cement, this was a matter to which engineers and contractors should give serious consideration. He agreed with Mr. Woodcock that cements vary in this respect, and in connection with their business he remembered his firm had found in one particular instance a considerable difference in the hardening of concrete where the aggregate had been the same, and different cements had been used. It was his experience that in nine cases out of ten the failure of concrete was attributed to the cement and invariably it was found after investigation that the cause of the trouble was not the cement, but the other materials used. It was surprising what little attention was given to the selection and grading of aggregate, and to the conditions under which concrete was mixed. Only recently his firm had under examination a piece of concrete forming part of an important structure which had failed. The cement used for the concrete had been tested before use, and was found to comply easily with the requirements of the British standard specification, but only a rough test of the aggregate had been made. The mixture was supposed to be 4 : 2 : 1, but on examination the concrete was found to be more in the proportion of 2 : 4 : 1, showing, of course, that it contained too large a proportion of fines. He would, therefore, strongly urge engineers and contractors to execise every possible care, not only in the mixing of concrete, but in the selection and grading of aggregate. Other consultants would, no doubt, agree with him on these points, and also that the advice they were frequently called upon to give as the result of their investigations was not so frequently acted upon.

The Author's Reply.

The engineer had specified for the work to be finished with 2 in. compressed asphalte and this was adhered to.

The author regrets he could give no exact return of the amount of water used, but care was taken to prevent any excess.

The cracks were decidedly pronounced at the kerb line and these measured in some cases 0·125 in. gradually lessening in width at 6 ft. from the kerb to 0·0625 in., and at the centre

16 ft. 6 in. to 0·001 in., these measurements being again repeated on the junction with the opposite kerb and at approximately the same distances.

In regard to the 802 foot section, only two appreciable cracks occurred. They were similar in their positions and measurements to those previously referred to. There were three others, but these did not measure at the widest point more than ·003 in. to ·001 in. and at times were not easily traced.

As to the work in which B.R.C. Fabric had been used, the only reinforcement was placed 2 ins. from the base, but this work was not left open for more than 7 days, whereas the previously mentioned cases approached a period of 21 days and none was less than 14 days.

The term aëration was used in preference to maturing as concrete will mature under any reasonable condition provided the materials were good and efficiently used, but the concrete that had the advantage of longer aëration is in a better condition to stand stress.

On Monday, May 1, 1922.

T. J. GUERITTE, B.Sc. (Paris), M.Soc.Ing.Civ. (France), F.S.E.,
PRESIDENT IN THE CHAIR.

THE TESTING OF SMALL ELECTRICAL PLANT (Part 2).

BY DR. C. V. DRYSDALE, O.B.E., D.Sc., F.R.S.E., M.I.E.E.

[*Being Part 2 of his paper of the same title read before the Society on March 6, 1922.*]

METHODS OF TESTING.

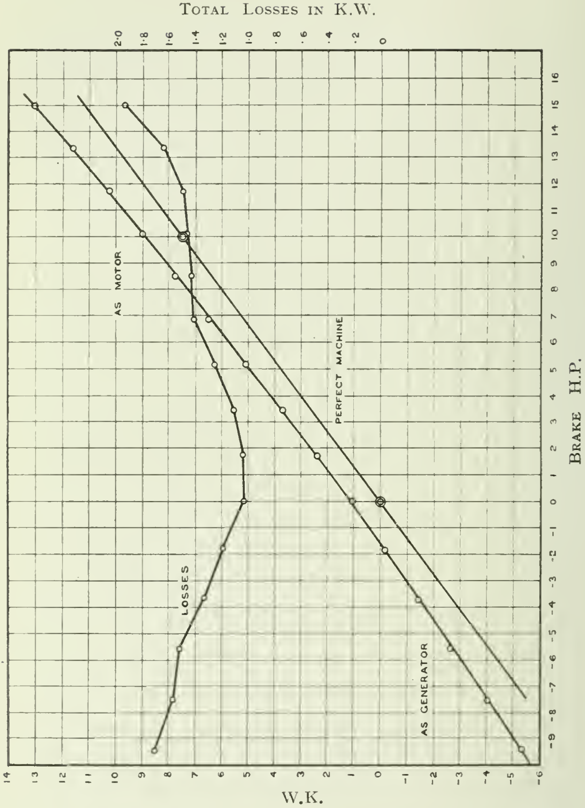
We will now consider the procedure adopted in testing machines of various kinds with examples of actual tests. As in each case the performance of a machine may be obtained either directly or indirectly by the separate measurement of its losses and the components affecting its regulation, both methods will be considered under each heading.

A, Direct Current Generators and Motors.—Assuming a regenerative brake of either the fixed or portable pattern to be available, direct current machines, whether generators or motors, can either be directly or indirectly tested without difficulty. After what has been said above, the direct method of test requires little description. The machine to be tested, whether motor or generator, is coupled to the regenerative brake, which is connected to the supply mains through its own panel; while the test machine is connected to the mains through the standard test board. The speed can be most accurately measured by the roller stroboscope run from a standard tuning fork, but a vibrating reed or other good tachometer will serve.

Figs. 1 and 2 show the results of direct tests made on a 15 K.W., 110 volt generator by the International Electric Co., of Liege. The capacity of the regenerative brake only permitted the machine to be tested up to 15 B.H.P. as a motor and to 5·4 K.W. as generator. The first curve shows the relation of output to input and the losses over the whole range, and the second the efficiency and other characteristics of the machine, both as motor and as generator. The regularity of the observations gives some indication of the accuracy of the method.

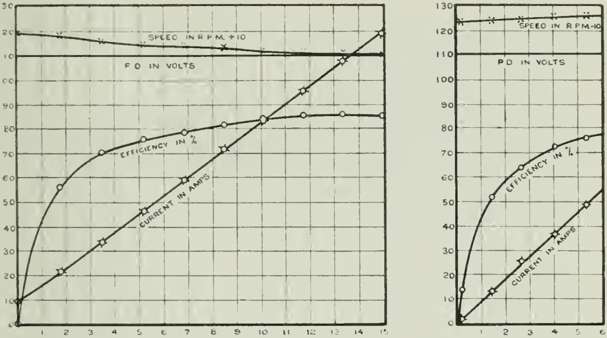
Coming to the indirect method, we first observe that for all machines running on constant P.D. the losses may be separated into two chief groups :—

(*a*) Fixed losses ; or those which are approximately independent of the load, *e.g.*, excitation losses, armature



TEST OF 110 V. D.C MACHINE BY REGENERATIVE BRAKE,

FIG. 1.



Output as Motor in B.H.P.

Output as Generator in K.W.

Test of 110 v. D.C. Machine by Regenerative Brake.

Fig. 2.

core loss, bearings and commutator friction, windage, etc.;

(*b*) Variable losses ; dependent on the load, *e.g.*, armature current losses, commutator losses.

If the machine is running either as a generator or motor at its rated speed or frequency and voltage, but without delivering any output, the power required to turn it will be the sum of the fixed losses, assuming that these, other than those required for excitation, are negligible.

On the other hand, if the machine is run as a generator or transformer at its rated speed or frequency, and the armature or secondary is short circuited on an ammeter, the machine being excited to deliver its full load current, the power required to run it is the sum of the variable losses and the friction losses, assuming the excitation required to be so small that the core losses are negligible. This same test enables the factors determining the regulation to be determined.

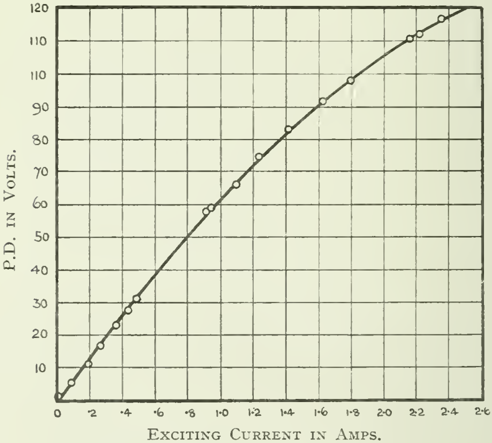
These two tests are generally known as the no-load and short-circuit tests respectively, and they are applicable to nearly every kind of electrical plant. For example in the case of a generator or motor, the no-load test running the machine light as a motor gives the sum of the copper and iron losses for excitation and the friction losses ; while the short circuit test using the dynamometer to run the machine as a generator gives the sum of the armature and commutation losses and the friction losses. The friction losses can be separately determined on the dynamometer by running the machine without excitation, and the whole of the losses of the machine are therefore determined, and can be analysed into their components by tests at various speeds or frequencies.

As an example, we will now consider the indirect tests of the above D.C. generator. The armature and brush contact resistances, etc., were first determined by passing a current through the brush leads and measuring the P.D. across the armature bars, etc., giving the following result.

Resistances in ohms :—

Brush holders.	*Brushes.*	*Commutator bars (Armature resistance).*	*R.H. brush and commutator*	*L.H. brush and commutator*
0·1101	·0940	·0283	·0283	·0683

It will be observed that the brush contact resistances are very high, and that the L.H. (positive) brush contact resistance is much higher than the other. The same test was therefore made with the armature rotated by the brake, care having been taken to demagnetise the field perfectly by reversals so that no E.M.F. was generated in the armature, and also to set the brushes exactly on the neutral axis, so that current passed through the armature



Exciting Current in Amps.
15 K.W. D.C. Generator Open Circuit Test.

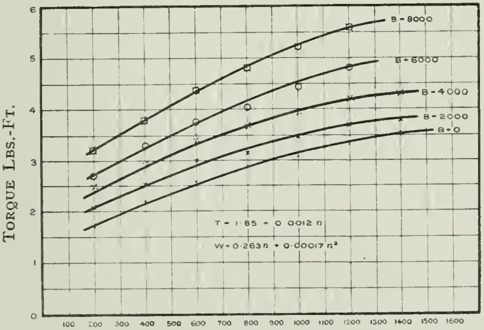
Fig. 3.

produced no reactive E.M.F. The resistances so determined were as follows :—

Holders.	*Brushes.*	*Armature.*	*R.H. brush.*	*L.H. brush.*
·0443	·0417	·02865	·003425	·003417

It will be seen that the contact resistances are much lower when the armature is rotating than when stationary, and that the difference between the positive and negative brush resistances practically entirely disappears. The total resistance between brush holders is only ·0443 ω, as compared with 0·1101 with stationary armature, and the C^2R loss at the full load current of 136 amperes 825 watts, instead of 1880 watts.

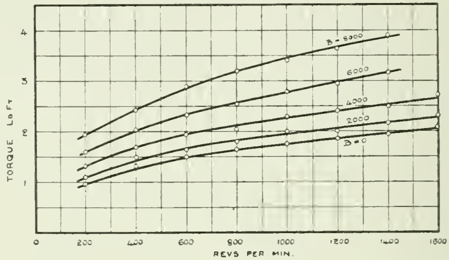
An open circuit saturation test was then made on the machine, running it from the small regenerative brake at 1000 revs. per min., and Fig. 3 shows the curve obtained. As the machine had 4 poles and 236 armature conductors with a two circuit series winding and the section of the iron in the armature was 143 sq. cm. the induction density in the core $B = 89000 \frac{E}{n}$ and the magnetising current required for various values of B could be scaled off from the curve, giving a value for B of 7600 for the normal shunt current of 1·9 amps. The torque required to run the machine on open circuit at various speeds and with different excitations was then determined on the brake. Fig. 4 shows a



SPEED REVS. PER MINUTE.
SPEED TORQUE CURVES.
15 K.W. GENERATOR.
RUNNING LIGHT, ALL BRUSHES ON.

FIG. 4.

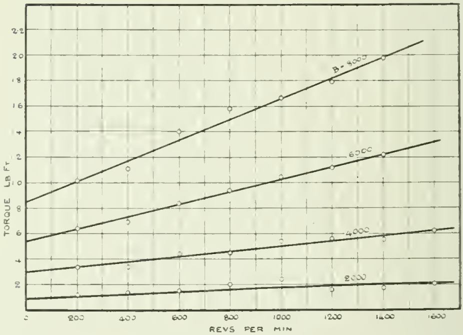
series of the curves obtained with all the brushes in position, and Fig. 5 a similar set with all the brushes lifted. The difference between the torques with brushes on and off, of course, gives the torque due to brush friction which averages about 2·0 lb.-ft. at the working speed and excitation corresponding to 310 watts loss in brush friction at 1200 revs. per min.



15 KW. D. C. GENERATOR

BRUSHES LIFTED

FIG. 5.



15 KW. D.C. GENERATOR

TORQUE-SPEED CURVES FOR CORE

FIG. 6.

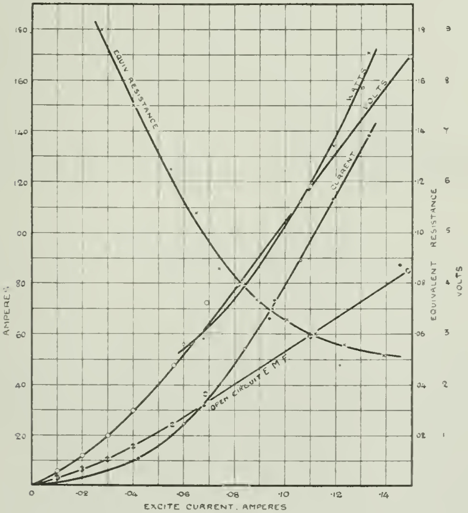
By subtracting the lower curve for B = 0 from the remaining curves in Fig. 5 we get the straight line curves in Fig. 6, connecting the torque due to hysteresis and eddy currents in the core with speed, while the lowest curve gives the torque due to bearing friction and windage—about 1·2 lb.-ft. for the former and 0·6 lb.-ft. for the latter at 1200 revs.

Analysing the above test we get the following :—

Bearing friction and windage	293	watts
Brush friction	310	,,
Hysteresis loss...	137	,,
Eddy current loss	160	,,
Shunt	210	,,
Total fixed losses	1,110	

Compared with the total loss of 1,020 watts at no load by the direct brake test.

At the normal full load of 136 amps the C^2r loss in the armature and brushes would be 825 watts, giving a total of 1935 watts, as compared with 1950 watts found from the direct test at 120 amps. This shows that the amount allowed for the armature and brush C^2r loss is insufficient, but a short circuit test was made on the machine as shown in Fig. 7. By comparing the short

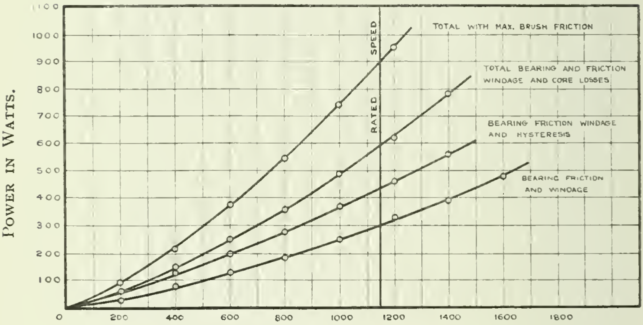


15 KW D.C. GENERATOR

OPEN CIRCUIT & SHORT CIRCUIT CHARACTERISTICS.

FIG. 7.

circuit current for a given excitation with the open circuit E.M.F. for the same excitation, the equivalent armature resistance can be obtained for each value of the current, and it works out at about $\cdot 06_{\omega}$ for a current of 119 amps, giving a loss of 850 watts, which added to the fixed losses gives 1960 watts, as compared with 1950 watts for the direct test at 119 amperes. The agreement between the direct test and the indirect estimate from analysis of the losses is therefore remarkably close, and the higher effective armature resistance must be ascribed to losses due to the short circuit currents in the armature coils at commutation.

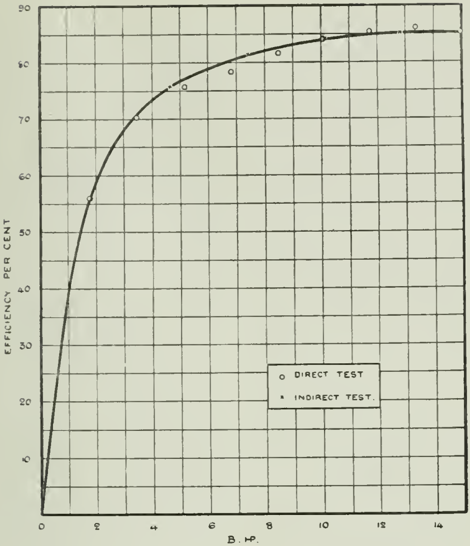


Speed in Revs. per Minute.
15 K.W. D.C. Generator.
Analysis of Losses.

Fig. 8.

Fig. 8 shows the variation of the various components of the frictional and core losses with speed, and Fig. 9 an efficiency curve for the machine running as a motor determined from these losses, the results of the direct test on the brake being shown by the circles. It will be seen that except for a small part of the range the direct and indirect tests are in close agreement.

Induction Motors.—The procedure in testing either single-phase or polyphase induction motors is the same, and is best illustrated by examples of actual tests of single-phase and three-phase motors.



EFFICIENCY CURVE FOR 110V. 15 KW. D.C. GENERATOR SHOWING RESULTS OF DIRECT & INDIRECT TESTS.

FIG. 9.

Figs. 10 and 11 show the results of direct tests on a 4 B.H.P. 100 V 50 ∾ 4 pole Heyland single-phase induction motor, tested on the large regenerative brake, both as a motor, and by running above synchronism as an asynchronous generator.

Fig. 12 shows a starting torque curve for a 3 B.H.P. 60 volt 4 pole 50 ∾ 3 phase induction motor with wound rotor and starting resistance taken by short circuiting the brake armature and balancing the torque as the motor crawls slowly round. Fig. 13 is a slip-torque curve for this motor taken over a considerable range below and above synchronism by means of the slip stroboscope, and Fig. 14 the circle diagram for this motor obtained by setting out the current for each load as a vector, the phase angle being determined from the true and apparent power. For large-phase angles the phase displacement ϕ is obtained from the relation $\cos \phi = \frac{w}{W}$

where w is the true power, and W the apparent power $= \sqrt{3}\ V\ C$, where V is the mean P.D. between lines and C the mean current in each phase. At high power factors, however, this method does not get an accurate result, but by arranging to reverse the current in one of the wattmeter moving coils, two wattmeter readings can be obtained, one w_1, when the two systems are

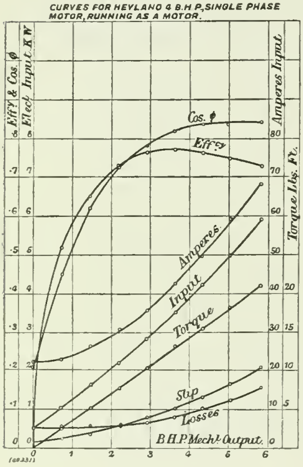


FIG. 10.

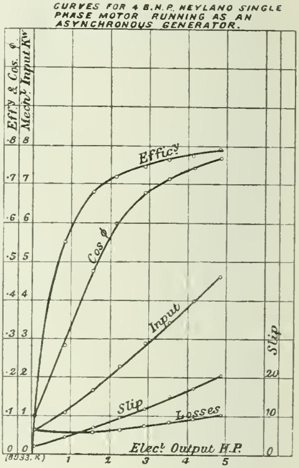


FIG. 11.

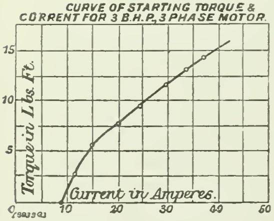


FIG. 12.

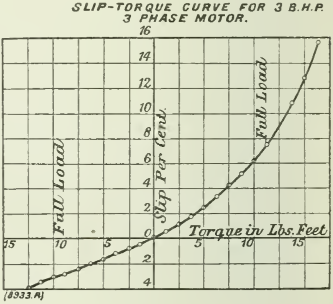


FIG. 13.

assisting and the other w_2 when they are opposing, and it can easily be shown that in this case

$$tan\ \phi = \sqrt{3}\frac{w_2}{w_1}$$

which enables the phase displacement to be accurately determined, even when small. This method has been adopted in many of the tests.

Figs. 15 and 16 are efficiency and loss curves for an 11 B.H.P. 6 pole 3 phase 220 volt

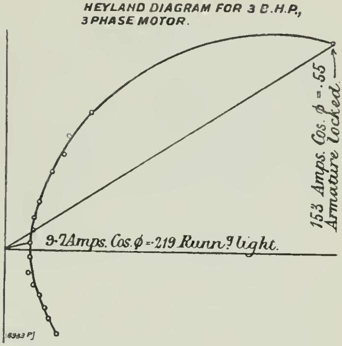

HEYLAND DIAGRAM FOR 3 B.H.P., 3 PHASE MOTOR.
153 Amps. Cos. φ = .55 Armature locked.
9·7Amps. Cos.φ = ·219 Runn.g light.
(6933 P)

FIG. 14.

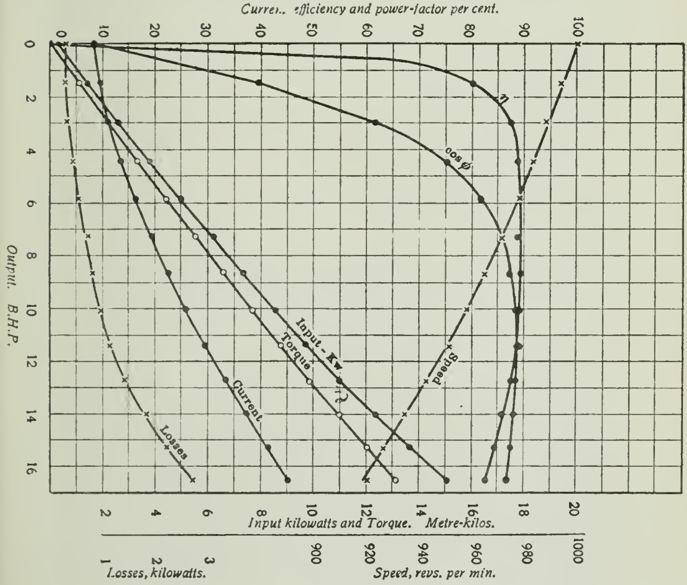


FIG. 15.—TEST CURVES OF E.C.C. 11 B.H.P. THREE-PHASE MOTOR.

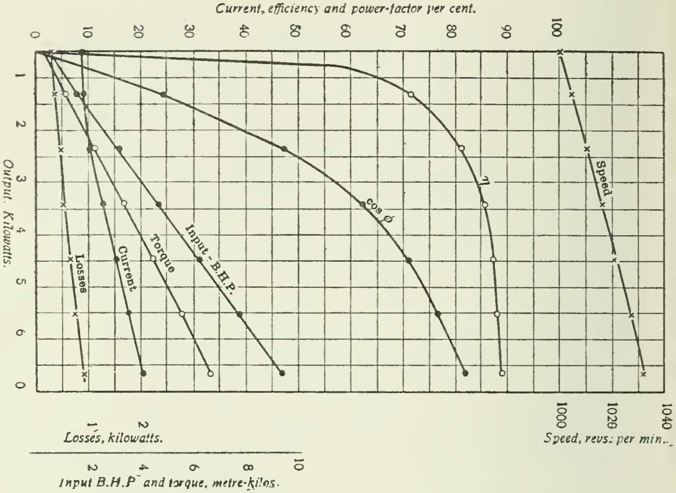


FIG. 16.—TEST CURVES OF E.C.C. THREE-PHASE MOTOR AS ASYNCHRONOUS GENERATOR.

50 ∿ E.C.C. induction motor with cage rotor tested between 16·5 B.H.P. as a motor and 7·5 K.W. as an asychronous generator.

Indirect Tests of Induction Motors.—In making indirect tests of induction motors it should be remembered that as they are rotating field machines, the true no load condition of the motor should be considered, as that when the rotor is rotating at the synchronous speed. In this condition with a polyphase machine the rotor bars are cutting no flux, and there is no torque on the rotor, so that if the electrical input is measured when the rotor is rotated at the synchronous speed by means of a small regenerative brake (as can be shown by a perfectly stationary stroboscopic figure illuminated by an arc or metallic filament lamp on the mains) the wattmeter shows the stator core loss plus the stator C^2r loss for the no load current, while the brake gives the bearing friction and windage torque at the synchronous speed and under running conditions. In the case of single phase induction motors where rotating field is produced by the reactionof therotor on the stator current, the wattmeter reading at synchronous speed gives the sum of the stator core loss and the stator and rotor losses at no load. If the brake is uncoupled the motor runs with a small slip due to the frictional torque, and the increase of the wattmeter reading gives the frictional losses. By locking the rotor or allowing it to turn very slowly on the short circuited brake, and exciting the stator with a fraction of its normal voltage we can obtain the " locked test " or relation between the current and power and the P.D. for a stationary rotor, and hence the dispersion co-efficient from which the circle diagram for the motor can be constructed, and its performance calculated. Figs. 17 and 18 show the curves for the no load and locked test

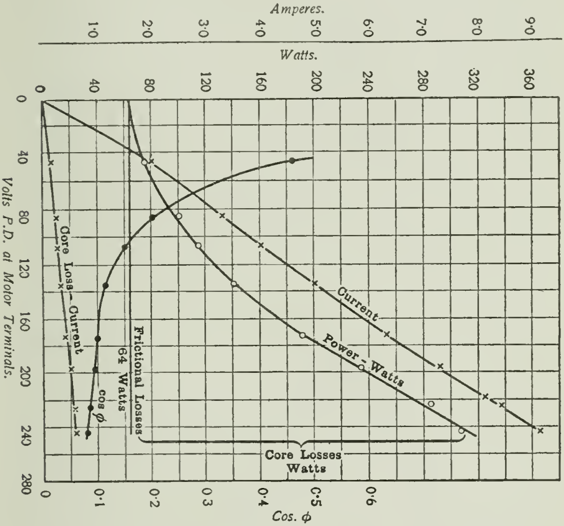


FIG. 17.—TEST CURVES OF E.C.C. MOTOR ; NO-LOAD TEST.

of the above motor, from which it will be seen that for the rated voltage of 220 the mean stator current per phase is 8·2 amps at a power factor of ·09, so that the magnetising current is 8·15 amps. The short circuit test was carried up to only 120 volts but extrapolating from this it would appear that the short circuit current for 220 volts would be 123 amperes at a power factor of about 0·35, or 160 amperes as the short circuit current for no reactance, so that the value of the dispersion co-efficient and for this motor would be 8·2/160 or ·0513. Circle diagrams have

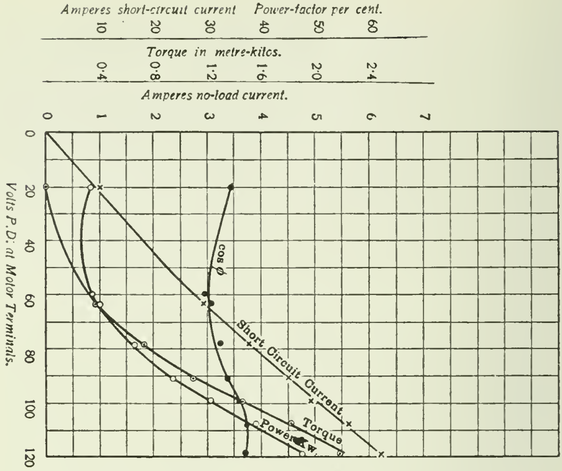


FIG. 18.—TEST CURVES OF E.C.C. MOTOR: LOCKED TEST.

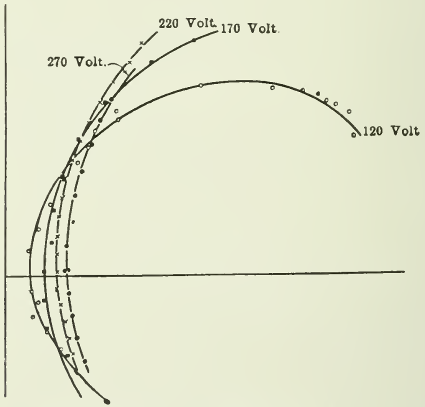
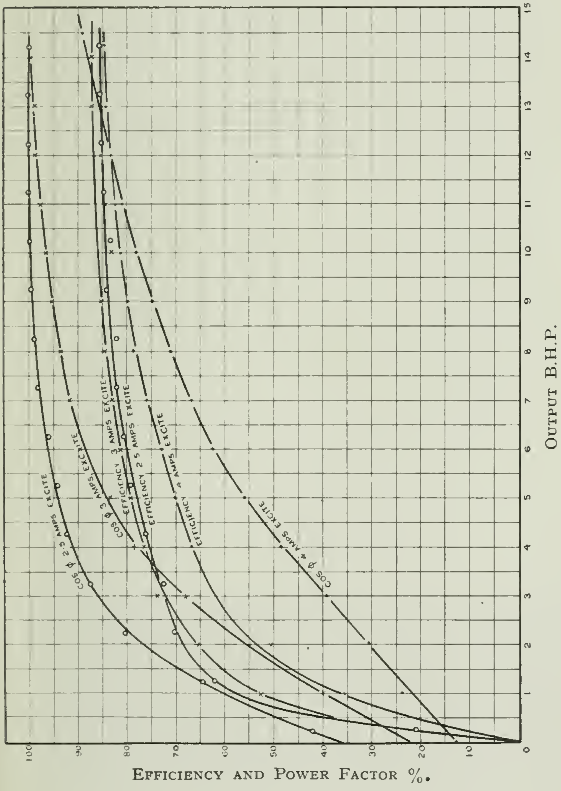


FIG. 19.—CIRCLE DIAGRAMS FOR THREE-PHASE MOTOR AT DIFFERENT VOLTAGES.

been prepared from this data and found to give results closely in accordance with the direct test.

Fig. 19 shows circle diagrams for this motor when run at various voltage determined directly from the wattmeter readings.

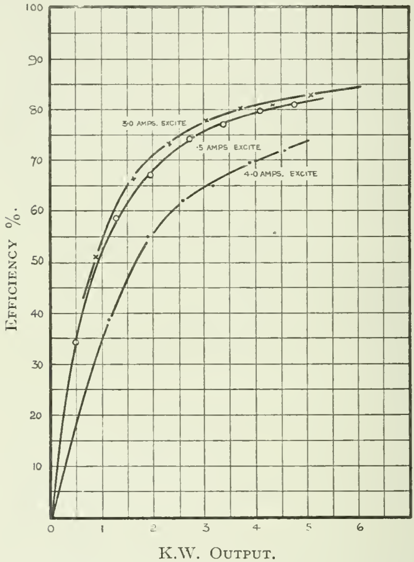
Synchronous Motors or Alternators.—The performance of synchronous motors depends greatly upon their excitation and Fig. 20 shows performance curves for a Brush 10 B.H.P. 3 phase



Efficiency and Power Factor Curves for 10 B.H.P. 3-Phase 220 V. Synchronous Motor for various Excitations.

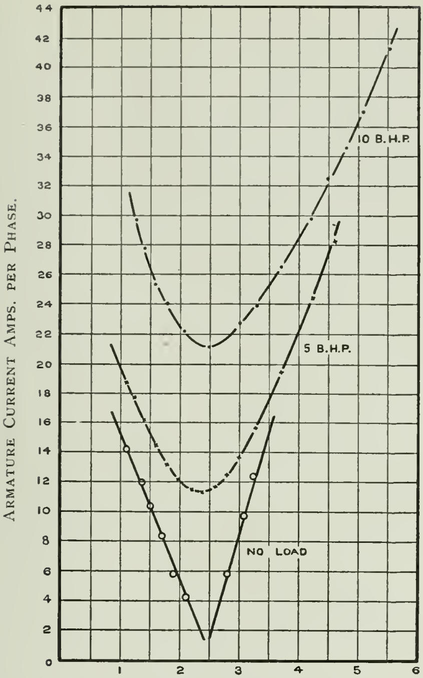
Fig. 20.

6 pole 220 volt 50 ∿ motor for values of the exciting current of 2·5, 3·0 and 4·0 amperes. It will be observed that the power factor for this machine is best for an excitation of 2·5 amperes, being actually unity at 12 B.H.P., but the efficiency at the larger loads is somewhat higher for an excitation of 3 amps. Fig. 21 shows efficiency curves for this machine driven as an alternator from the brake and running the driving alternator as the synchronous motor. Fig. 22 shows a set of " V "curves for the motor when running light, on a 5 B.H.P. and on a 10 B.H.P. load respectively, and shows that the armature current taken by this machine at any load depends greatly on the exciting current, being a maximum for 2·4-2·5 amperes in each case. The corresponding changes of phase angle determined by the method of reversing one of the wattmeter pressure coils described at p. 4, are shown in Fig. 23, which indicates the great extent to which an over



Efficiency Curves for 10 B.H.P. 3-Phase 220 V. Synchronous Motor Running as Alternator.

Fig. 21.

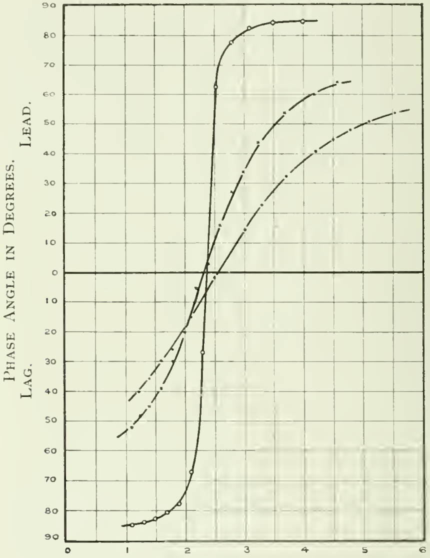


"V" Curves for 10 B.H.P. 3-Phase 220 V. Synchronous Motor.

Fig. 22.

excited synchronous motor can act as a leading load or condenser for compensating a lagging load on the mains. For example, when running light with 4 amps, exciting current the motor takes over 19 amperes per phase with a lead of about 85°, when running at full load with an exciting current of 5 amperes it takes about 36 amperes per phase leading 50° or 27·6 amperes per phase. The motor ran quite well under these conditions, although there was a certain tendency to hunt at some loads.

Indirect Tests of Synchronous Motors or Alternators.—By running the motor or alternator on open circuit from the regenerative brake we determine the bearing friction and windage loss, when the machine is unexcited, and the core loss by exciting it. We can further determine the open circuit saturation curve or relation between the armature E.M.F. and the exciting current

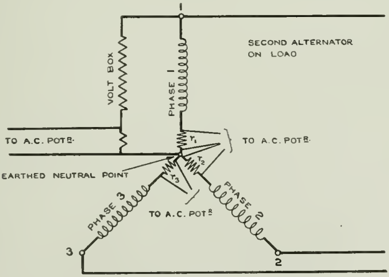


Variation of Phase of Current with Excitation for Brush 220 V. 3-Phase Synchronous Motor.

Fig. 23.

by running it from the regenerative brake at constant speed and varying the excitation, having carefully demagnetised the magnets. By running the motor at synchronous speed, short circuiting the armature through an ammeter, and exciting it until the full load current is developed, we can measure the armature copper losses on the brake, and at the same time determine the excitation required to overcome the armature reaction and inductive reactance. We therefore have all the components of the losses of the machine from which we can predict its efficiency. The regulation can also be predicted from the no load and short circuit characteristics, by the method of Torda Heymann, which is equivalent to assuming that the drop is due to armature reaction increased in proportion to the square of the reluctance of the magnetic circuit. A number of tests of this character have been made on a 25 K.V.A. 3 Phase alternator specially designed and built at the Northampton Institute, but the data are unfortunately unavailable at the time of writing. A number of the above motor tests were made on this alternator, in which each of the three phases were wound with two coils which could be joined in series or parallel. By means of a special commutator on the switchboard the winding could be connected either in series or parallel, and in star or delta grouping, giving a wide range of voltage from the same machine. The principle might well be extended by winding the armature with say ten independent windings for connection in series or parallel with a commutator of the type employed in the wattmeter, enabling P.Ds. of 100 to 2,000 volts to be obtained from the machine without transformers.

Testing of Large Alternators.—Although this question does not come strictly within the scope of this paper its importance is so great, that a few words may be devoted to it. With polyphase generators of high voltage and large current the use of ordinary wattmeter is almost prohibitive, both on account of cost of apparatus and danger of breakdown. In this case the best course would probably be to introduce three non-inductive resistances between the inner ends of the 3 phases (see Fig. 24) and the neutral point, each resistance giving a drop of 0·1 volt or less at the full load current. If the central point of these resistances is earthed, and a high resistance volt box giving a drop of 1 volt or



Testing of Large Alternator by Potentiometer.

Fig. 24.

less is connected between the neutral point and cipher terminals 1, 2 or 3 of the generator, the P.D. and current and the phase difference between them, can be directly read off on the potentiometer for each of the three phases without danger, and the total electrical power developed by the alternator $= V_1 A_1 \cos \phi_1 + V_2 A_2 \cos \phi_2 + V_3 A_3 \cos \phi_3$, the alternator being loaded on the mains or on another alternator whereby the power factor can be controlled by varying the excitation as in the case of the synchronous motor above. As regards the mechanical input, this can be determined directly by the steam consumption in the case of a combined set, or it might be obtained by a suitable transmission dynamometer.*

Transformers.—Fig. 25 shows the results of a direct test of a 2 K.V.A. 2,000/100 volt 50 ~ Westinghouse transformer on non inductive secondary load. In this test one wattmeter only was employed in the low voltage side, the secondary load being determined by the product of the P.D. and current on a 2,000 volt lamp load.

A more accurate method of testing single phase transformer with a ratio of transformation of not more than 20 or 30 to one would be by employing a double wattmeter to determine the total losses directly, the primary coil being connected to one system of the wattmeter and the secondary to the other, care being taken that the two systems are in opposition. By employing keys in the pressure circuits either can be broken, and readings can be obtained successively of the primary input, the secondary output, and to the difference giving the losses direct. For example, if it is required to test a 10 K.V.A. 2,200-110 volt transformer, a 100 ampere double wattmeter would be used, the low tension side being connected to one system of the wattmeter with the commutator set to all parallel, and 5000 ω in the pressure circuit. The other system would have its commutator set to all series, with a pressure circuit of 50000 ω, giving the same constant on both systems. With the connections as shown the secondary is always loaded by the wattmeter pressure circuit or by a power $= \frac{V^2}{R}$, so that if $V = 2200$, and $R = 50{,}000$, the power in the pressure circuit is 96·8 watts, which must be deducted from the losses read by the wattmeter.

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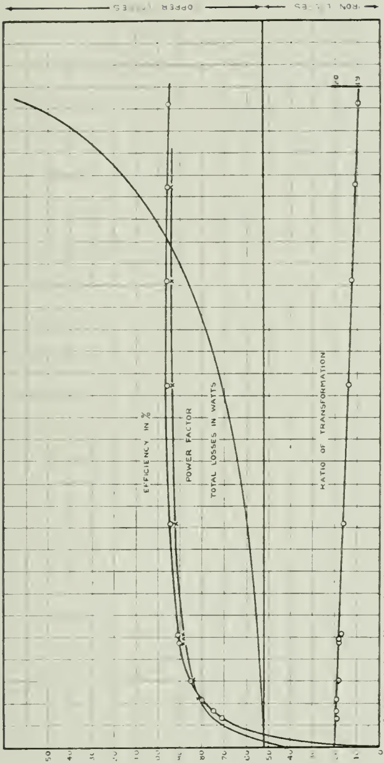
*In the discussion on the first part of this paper, Dr. Rayner expressed a preference for a watt-meter employed with current and potential transformers to the above A.C. potentiometer method. The author's experience with current transformers has led him entirely to distrust their use with watt-meters on account of their large phase displacement, but he has since been informed that there is one make of watt-meter with current transformers which are extremely satisfactory. In this case there can be no question that this device would be far more convenient than the potentiometer method.



APPARENT WATTS.

TEST OF 100-2,000 VOLT 2 K.W. WESTINGHOUSE TRANSFORMER.

EFFICIENCY AND POWER FACTOR %.

FIG. 25.

As regards loading the transformer, this may be done on any water or other load, but if a number of similar transformers are to be tested a " loading back " method, similar to that proposed by Dr. W. E. Sumpner, D.Sc., may be adopted, except that it is of no importance where the two transformers are identical in efficiency. If tests are to be made at various power factors, the most convenient method in this case is to use a phase shifting transformer which injects an E.M.F. at any desired phase angle lagging or leading between the secondaries of the two transformers.

A phase shifting transformer devised by the writer for wattmeter and supply meter testing is also suitable for this purpose. It is constructed for either single or two phase, or for 3 phase circuits, and the latter form can be used if necessary for testing three phase transformers.

In the case of rotary converters or motor alternators sets, these can be tested in a similar manner to ordinary A.C. transformers, as the wattmeter and other instruments will read equally satisfactorily on A.C. or D.C. circuit.

Indirect Tests of Transformers.—Large transformers are usually tested indirectly by the no load and short circuit tests. Both of these tests can be made directly with the standard testing connections. In the no load test the transformer is excited at the rated voltage and frequency and the true and apparent power obtained from the ammeter, voltmeter, and wattmeter readings giving the core loss and the magnetising current. This test can be made over a small range of voltage corresponding to the drop in the transformer at full load, which is, however, very small in a good large transformer. For the short circuit test the secondary of the transformer is short circuited, and a low voltage at the rated frequency applied to the primary, the ammeter, voltmeter, and wattmeter readings being taken as before. The ratio of P.D. to current gives the equivalent impedance of the transformer windings which can be separated into the resistance and reactance by the aid of the wattmeter reading. In cases where the reactance is relatively small, greater accuracy can be obtained by interposing a condenser in the wattmeter pressure circuit in substitution for the ordinary non-inductive resistance. This changes the phase of the current in the moving coil by nearly 90°, and makes the instrument very sensitive to small reactances. When the core loss and magnetising currents and the equivalent resistance and reactance of the windings have been determined from these two tests the vector diagram of the transformer can be constructed, and its efficiency power factor, and regulation determined for various condition of loads.

The only objection to this indirect method of test is that the equivalent resistance and reactance of the windings are determined with the core at a low stage of saturation, and as the regulation of transformers which are to be worked in parallel is of the most extreme importance in order that they should share the load equally, the writer has devised a method in which the regulation is determined under working conditions* In this case the transformer is connected to the supply in the ordinary manner and is loaded either directly or by a "loading back" method. An auxiliary transformer of small output, but of approximately the same ratio of transformation is fed from the same mains, and a wattmeter with resistance or condenser in its pressure circuit, or an alternate current transformer is employed to measure the two components of the difference between the P.D. of the two transformers as the transformer under test is loaded, as desired.

CONCLUSION.

In conclusion it is greatly regretted that want of time and dispersal of certain papers during the war, has prevented a more nearly perfect presentation of the subject. The results above given do not represent a tithe of the work which has been done on all classes of motors and transformers, but it is hoped that they will suffice to show what accurate work can be done in the testing of small electrical plant by the devices described. There can be no doubt whatever that the combination of the regenerative brake with the multi-range wattmeter and ammeters, and the stroboscopic devices, makes the testing of machines and analysis of their losses possible with a very high degree of accuracy and with a very reasonable outlay of plant and time in testing, an outlay that would be rapidly recouped (apart from the value of the results to the designer) by the economy in testing rendered possible by having a well laid out outfit. With a few well-trained observers, tests of the accuracy shown above could be systematically carried out at no greater, if not less, cost than the crude tests ordinarily made, and as said at the outset, the possibility of issuing accurate performance curves of machines and the stimulus to healthy rivalry and improvement, would do an immense amount to raise the prestige of the British Electrical Industry. It is therefore earnestly hoped that our manufacturers will give serious consideration to this subject and adopt the above, or better methods if they can be found, for obtaining and publishing reliable tests of their products.

The author's thanks are cordially tendered to his old colleagues at the Northampton Institute, especially to his Senior Demonstrator, Mr. A. C. Jolley, who gave valuable help in designing the apparatus and conducting the tests, as well as to Messrs. F. Gerrard, C. M. Down, and A. F. Burgess, who assisted in the tests and calculations.

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*The testing of Transformer Regulation ; *Electrician*, July 29, 1910.

DISCUSSION.

Mr. W. B. Esson, M.I.C.E., M.I.E.E., said he had much pleasure in seconding the vote of thanks to Dr. Drysdale for his interesting and instructive paper. In electrical papers "lead" and "lag" were frequently referred to, but the speaker was that night suffering from a kind of lag which was not altogether electrical and that was the lag of a mind which refuses to be carried back all of a sudden to a time thirty years gone by, when the testing described by Dr. Drysdale was a familiar everyday occurrence, that mind having been engrossed with other matters, many of them much less interesting, in the interval. He had not had an opportunity of reading that part of the paper and Dr. Drysdale had lectured at such a speed and had told them so much in so little time that he could not possibly get his grey matter to respond to his high frequency, consequently, it was only here and there that he was able to get into synchronism with him for a brief time. There were very few small transformers now-a-days such as the author referred to, but he remembered when they used to be made by the thousand. In these days, when there was alternating current distribution, large transformers in sub-stations reduce the pressure to the consumer's requirements and a low-pressure network gave the supply. In the old days, every house had its own small transformer and the high pressure current was brought on the premises of each consumer. He remembered the firm he was with getting an order for a large number of transformers from an important London supply undertaking. The specification for those transformers was, as regards iron and copper losses, a very stiff one indeed, but they took their reputation in their hands and with all the knowledge they possessed engaged on the design. In due time the transformers were delivered and they thought they would pass the merciless tests to which they were to be subjected and come within the limits as regards losses. They waited patiently for the results of the tests and for the money and at last got the former. Taking the figure allowed for losses, we were to have a bonus for under and pay a penalty for over the figure, and they were asked whether they accepted the purchaser's result. Naturally their designers did not want to accept any figures without going through all the calculations again, but as he pointed out that all the *plus* and *minus* adjustments only made one per cent. difference in the price, he induced them to pocket their pride, save their time and accept the figures without more to do. With that little incident showing how he used to harmonize theory and practice and once more thanking Dr. Drysdale for his paper, he would resume his seat.

Dr. Herbert Chatley, D.Sc.(Engineering), A.M.I.C.E., expressed his appreciation of the paper and asked why the "contact resistances were much lower when the armature was rotating than when stationary." He could conceive various reasons why this might be, but as it was a question of great interest, both from the designers' and the physicists' points of view, he would be glad of a definite opinion on the point.

Mr. M. Holroyd Smith, M.I.E.E., said the reference of the last two speakers aroused old memories in his mind, he felt like an old charger for a long time relegated to the home for tired horses, which, when he hears the beating of the drum and tramp of feet, pricks his ears and wants again to join the regiment.

They, the last speakers, had spoken about carbon brushes : as far back as 1884 he adopted carbon brushes and thought he was one of the first to do so. He used the stumps or tag ends of carbons used for arc lamps. They were held in little clamping claws, at the free ends of four steel fingers on each side of the commutator, each pair of fingers being drawn together, and thus on to the commutator, by elastic rings passed round them. They were thus easily renewed and adjusted. By using different elastic bands or giving them a twist, the pressure of the carbons on the commutator could be regulated and the eight fingers evenly distributed the pressure.

Mr. William Brooks Sayers, said he was engaged in the production of a new type of dynamo electric machine, the characteristic features of which enable much higher efficiencies to be attained than had been possible hitherto, accompanied by a large increase in output per unit size and weight.

The efficiency of electric motors and generators was nothing to boast about. It was all very well to say that 85 per cent. left but 15 per cent. to work upon, but with double transformation as in a transmission scheme there was only 72 per cent. delivered at full load and much less at lighter loads. Hence electric efficiencies were a long way behind that of mechanical gears.

The new type machine he was developing would reach at least half-way towards 100 per cent. or say to 92½ per cent. or higher with saving of cost in material and labour and also saving in weight.

Dr. Drysdale had rightly said that the analysis of losses was most important to the designer because if he had to minimise them he must know where and how and in what form and in what relative amounts they occurred. In the first part of his paper Dr. Drysdale spoke of several things he had done " 20 years ago." On referring, he found it was just 20 years since he read a paper before the Institution of Engineers and Shipbuilders in Scotland (Glasgow), in which various losses were separated (see Vol. XLVI., 1902-3, Proc. of Inst. of E. & S. in Scotland, p. 217-47).

In his examples, Dr. Drysdale took the light load losses and added thereto the C2R losses at full load and found the total agreed with the total full load losses. It was not generally found that the losses—hysteresis eddies, etc., were the same at full as at light loads, though they might be approximately determined in the way referred to—the close agreement shown in the paper was somewhat exceptional.

Reference was made to the difference in the contact resistance of carbon brushes when the machine was standing, compared with when it was running. This could be explained from the undoubted fact that a block of unyielding material could not in practice really touch over the whole of the surfaces in juxtaposition especially when the cylindrical surface (the commutator) was a little worn and there was perhaps some end play. No doubt the block touched at one or two points in uncertain fashion. When the machine was rotated, an average condition obtained and a comparatively steady value resulted. Dr. Drysdale's figures showed how great was the proportion of loss at the carbon brushes.

THE AUTHOR'S REPLY TO THE DISCUSSION.

Dr. Drysdale, in reply, thanked the various speakers for their appreciation and for the interesting points raised. He was sorry to have dealt with the subject in such a hurried fashion, but the ground to be covered was very large, and there were many parts of it such as the accurate determination of heating and of transformer regulation which he had not been able to deal with. However, the discussion had shown the importance of the subject, and he was especially glad of the comments from the two great pioneers of practical electrical machine design, Mr. Esson and Mr. Sayers, whose first papers on the subject appeared while he was still a student, and were the only guide to design for many years. He felt that Mr. SAYERS, who was still actively engaged in perfecting dynamo machinery, had struck the right note in pointing out that there was still great room for improvement, and that accurate testing of the various losses was the great guide to the designer in securing such improvement. This was the point he had emphasised in his paper, and he was glad to see it endorsed by one who was so thoroughly conversant with practical design.

The question of carbon brushes was an important one, and he was interested to hear of Mr. Holroyd Smith's claim to have been the pioneer in their introduction. The introduction of carbon brushes had certainly been a great step in securing sparkless commutation at all loads without the irritating changing of lead of the brushes they used to have to contend with, but he could not help feeling that there was a reverse side to the question, as the use of carbon brushes had certainly resulted in a great diminution of efficiency from the high values which used to be obtained with gauze brushes, both on account of larger frictional losses, and the considerable electrical resistance loss in the brushes and contacts. No doubt the high contact resistance found with carbon brushes when the machine was at rest was largely attributable to imperfect bedding, as Mr. Sayers had suggested, but the effect did not appear to be one simply of small area of contact as there was the great difference of apparent resistance between the contacts of the positive and the negative brushes, which had been noticed by many observers, and which appeared to resemble the effects obtained in crystal rectifiers. The point was of considerable theoretical interest, but the methods he had employed for determining the contact resistance during rotation by the fall of potential and short circuit tests showed that this resistance was much lower, and that the asymmetry disappeared during rotation, so that it was of little practical importance.

The point raised by Mr. Sayers as to the discrepancies usually found between the working efficiency of a machine and that determined from the separate determination of its losses was an important one, as it affected the whole question of whether indirect tests of machines were valid. His own methods of indirect testing, using the short circuit method, had been especially devised on account of this difficulty, and to make the tests of losses as nearly as possible under working conditions, and the close correspondence between the results of the direct and indirect tests he had shown was probably to be attributed to these methods, and appeared to justify them. He sincerely hoped that Mr. Sayers would be successful in gaining his great increase in efficiency, and would be glad of an opportunity of seeing his new machine. It would appear from his own tests that nearly half the total losses in a carbon brush machine were due to frictional and electrical losses in the brushes, so that this was evidently the great point to attack. Obviously, the desiderata for improvement in this direction were low friction combined with low contact and linear resistance of the brushes, but with high transverse resistance to check sparking, and the solution would appear to use a laminated metal brush with insulating laminæ between the metal leaves so as to give a long path for the short circuit currents.

LOCOMOTIVES OF THE L. & N. W. R.*

By C. F. Moore, of the Crystal Palace Engineering Society (associated with this Society).

In a historical sketch of the locomotives of the L. & N.W.R. it is necessary to go back a great many years to the construction of the " Rocket," in fact, to 1829. Although this engine did not run on what was then known as the L.N.W.R., it belonged to the Liverpool & Manchester Railway, a company, which, together with 56 others, amalgamated to form what is known and generally acknowledged to be the premier line of Great Britain. The " Rocket " is too well known to need much description. On April 20th, 1829, the Liverpool and Manchester Board offered a premium of £500 for the locomotive which would fulfil in the most efficient manner the conditions laid down by the Board. The conditions were, briefly, that the engines were not to weigh more than 6 tons, the boiler pressure to be under 50 lb. per square inch, two safety valves were to be fitted, and the minimum load was to be three times the weight of the engine, and the minimum speed 10 miles per hour. At once all the locomotive designers of the age started to construct locomotives, and George Stephenson was among them.

The dimensions of the well-known engines were as follows :—

Weight, 4 tons.
Adhesion weight, 2 tons 10 cwts.

The date of the trial was fixed for October 1st, but subsequently postponed to October 6th.

There were four competitors, the engines and designers being as follows :—

1. Braithwaite & Erission's " Novelty."
2. T. Hackworth's " Sanspariel."
3. R. Stephenson & Co.'s " Rocket."
4. Burstalk, " Perseverance."

It is unnecessary to discuss the performances of the competitors at length, it being sufficient to say that the " Rocket " was the only locomotive to fulfil the conditions, and, with a load of 13 tons, it made 20 trips, occupying altogether 3 hours 51 minutes, at an average speed of 15 miles per hour, and a maximum speed of 29 miles per hour, thus proving to the crowds who watched the test that the steam locomotive was a practical success. Some days later the famous engine was credited with the marvellous speed of 35 miles per hour, and the £500 was awarded to the owner.

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* This paper was awarded the Geen Premium in 1921 for members of Associated Societies.

Other engines constructed for the line were the "Northumbrian," "North Star," "Phœnix," "Dart," "Meteor," "Arrow," and "Comet." A later engine, the "Planet," is famous for the fact that on December 4th it hauled a train weighing 80 tons from Liverpool to Manchester in 2 hours 54 mins. It is on record that this engine once brought a party of voters from Liverpool to Manchester in 60 minutes.

In 1831 the "Goliath" and "Samson," engines of an improved type, were delivered by Stephenson, and astonished the public by hauling a train of 150 tons at a speed of over 19 miles per hour.

On July 16th, 1846, the bill for the amalgamation of the London and Birmingham and Grand Junction Railway, under the name of the London and North Western Railway Company, was brought out.

The locomotive department was divided into the northern and the southern sections.

In 1848 Mr. Crampton, then locomotive engineer of the southern division, built the "London," a 4-2-2 locomotive, with driving wheels 8 ft. in diameter, and two cylinders 18 ins. × 20 ins. The boiler was oval, and the firebox was continued beneath the driving axle. This was the first named locomotive in the southern division, and an illustration is appended.

The contemporary engineer on the northern section was Mr. Allan. One of his 2-4-0 "Crewe" goods engines, and a 7-6 single are illustrated herewith.

Mr. F. Trevithick became locomotive superintendent of the northern division in 1848. He was formerly in charge of the locomotive department of the Grand Junction Railway. He occupied the position from 1848 to 1857, and during this period many well-known locomotives were built, including the famous "Cornwall," which is illustrated herewith in her original condition as built with boiler slung beneath the driving axle, and also in her rebuilt form by Mr. Ramsbottom in 1858.

The chief dimensions of the "Cornwall," as originally built, were as follows :—

Driving wheels, 8 ft. 6 ins. dia.
Cylinders (2), $17\frac{1}{2}$ ins. × 24 ins.
Heating surface, 1,046 sq. ft.

Probably there is no locomotive in the world to which so much historic interest is attached as to the "Cornwall." She holds the record to-day of being the oldest locomotive running in the British Isles, albeit her duties only extend to the hauling of the engineers' inspection coach, on which work she is credited with many excellent speed records. In her original condition it is said she once reached 117 miles per hour.

In 1857 Mr. Ramsbottom succeeded Mr. Trevithick as locomotive engineer of the whole of the London and North Western Railway. In 1858 he built the "Lady of the Lake," a 7 ft. 6 ins. 2-2-2 single, with outside cylinders 16 ins. × 24 ins. An illustration of this type is appended. They were justly famous engines in their day, but have all since been relegated to the scrap heap.

Weights, in working order :—
Engine, 31 tons 7 cwts.
Tender, 25 tons 0 cwts.
Total, 56 tons 7 cwts.

In May of 1863 Mr. Ramsbottom turned out the first of a new class of 2-4-0 main line engines, with 6 ft. coupled wheels, known as the "Samson" class, of which 50 were built between May, 1863, and January, 1866. Mr. F. W. Webb, who took the reins of government at Crewe some time later, added 40 more between 1873 and 1879. Much controversy exists over this class of locomotive, and the following particulars may be useful in order to explain what is known by many as a "dual identity" class of locomotives. They were small engines, and even in their prime were relegated to much mixed traffic work, and so, in 1889, a process of renewal was begun, beginning with No. 1,045, "Whitworth." So complete was this renewal that though they were nominally rebuilt, in reality they were succeeded by entirely new engines. The dimensions before and after renewal were as follows :—

	As originally built.	*After rebuilding.*
Cylinders ...	16 ins. × 20 ins.	17 ins. × 24 ins.
Coupled wheels	6 ft. 3 in.	6 ft. 3 in.
Heating surface	1,083 sq. ft.	1,102 sq. ft.
Boiler pressure	120 lb. per sq. in.	150 lb. per sq. in.

A longer wheel base and Allan's link motion, in place of Stephenson's, were also alterations made in the reconstruction. Originally they had open-work splashers, and no cab, as shown in the sketch. Mr. Webb modernised them slightly when he built his 40 engines, giving them a cab, and, in a later series, also enclosed splashers. It was only in the complete reconstruction, however, that an enlarged boiler and lengthened frame was fitted.

In 1886 Mr. Ramsbottom introduced the "Newtons," with 6 ft. 6 ins. coupled wheels and enlarged boilers. Mr. F. W. Webb took the "Newtons" in hand on becoming locomotive superintendent, and they were virtually renewed as the "Precedents," and in their renewed state, achieved a justly famous reputation, while in combination with the rebuilt "Whitworths," they realised a wonderful reputation for locomotive performances, and they have many notable records on the steeply graded northern main line. All the original 90 engines of the "Whitworth" class were scrapped between 1889 and 1896.

With regard to the "Precedents," the following examples of their records will serve to demonstrate their undying fame. The races between the East and West Coast Routes from London to Scotland are too well known to need description, and while the palm of the Edinburgh race is usually awarded to the eastern companies, the victory of the race to Aberdeen is almost universally said to belong to the L.N.W. and Caledonian Railways. The race through which this great victory was obtained is worthy of a detailed record, and it is here where the "Hardwicke," a "Precedent," shone so brilliantly. On August 22nd, 1895, the 3 cylinder 7 ft. compound "Coptic" left Euston with 70 tons at 8 p.m., and reached Crewe at 10.28. At 10.30 the train left Crewe with "Hardwicke," the 6 ft. 6 in. "Precedent." From Crewe to Carlisle there exists the Shap incline, generally acknowledged to be the most difficult on an English main line. "Hardwicke" covered the total distance at an average speed of 65·1 miles per hour, thereby achieving an unheard-of record. The whole distance between Euston and Aberdeen was covered at an average speed of 63·3 miles per hour, including stops. The last time the author saw "Hardwicke," she was on a mixed goods train on the Birmingham branch—"How are the mighty fallen!"

The other record is that owned by the late "Charles Dickens," a locomotive of the same class, which completed 2,000,000 miles, thereby holding the world's record for the mileage of a passenger locomotive. The name now belongs to a 4-4-0 superheater "George V."

The "Precedents" were the last simple express engines to be built by Mr. F. W. Webb, and were followed by a great number of compound engines of many classes and types. This brings us to a very interesting chapter in the locomotive history of this line, as it opens up the greatest question connected with locomotive design—the compound and the simple. For many years this famous designer fought a long and an uphill battle in his great efforts to convince the locomotive world that the compound engine was a practical and an economical improvement on the simple, and he fought his great battle alone among the engineers of Great Britain. It was a great and splendid battle, and calls forth the greatest admiration for the pluck and perseverance of this great man in the face of so many failures, for, of the many classes he constructed, not more than one or two can be said to have been complete successes. He started in April, 1882, with the "Experiment," herewith illustrated, of which 30 were constructed between that date and October, 1884. Although accounts of the trial trip of the " Experiment " appear to describe it as a success, it is generally acknowledged that, as a class, they were a failure. Nevertheless, they were extremely interesting engines, and especially does this apply to Mr. F. W. Webb's " divided drive," which obviated the use of coupling rods. The one low-pressure cylinder, measuring 26 ins. dia. × 24 ins. stroke, was placed inside, and drove the leading driving axle, while the two outside 13 ins. × 24 ins. high-pressure cylinders drove the trailing axle, the axles being uncoupled. Whatever theoretical disadvantages a coupling rod may possess, they are certainly outweighed in practice by the extra adhesion and synchronising of the driving wheels obtained by their use.

The chief dimensions were as follows :—

Coupled wheels, 6 ft. 6 ins.
Weight, 37 tons 15 cwts.

In 1884, the " Experiments " were followed by the " Dreadnoughts," similar, but larger and more powerful engines, of which 40 were built. They were said to have had a larger degree of success than the " Experiments," though by no means satisfactory.

In 1899 came Mr. F. W. Webb's third class of compounds, the 10 " Teutonics." These were undoubtedly Mr. Webb's *piece de resistance*, and were great favourites with the drivers and the travelling public alike. " Jeanie Deans," of this class, for many years ran the 2 p.m. express Euston-Crewe train, weighing 300 tons, while the " Tonic," also of this class, covered the 299 miles from Euston to Carlisle without a stop, on September 8th, 1905, a world's record.

In 1891, 10 eight-wheeled 2-(2-2)-2 compound engines appeared, known as the " Greater Britains." They had 7 ft. 1 in. driving wheels, similar to the " Teutonics," this being the reason through which the latter were said to have achieved their brilliant success. The " Greater Britains," however, though successful engines, never aspired to the brilliancy of their predecessors.

In 1895 came the 10 " John Hicks," in which Mr. Webb reverted to 6 ft. driving wheels, and which were generally said to have been dismal failures. Why Mr. Webb ever gave up the 7 ft. drivers through which the great success of the two earlier classes were said to have come, is a complete mystery.

In 1897 Mr. Webb launched into building 4-cylinder compounds, with a leading 4-wheeled truck, which technically was not a bogie. The class was known as the " Jubilee " class, after " Diamond Jubilee," the initial engine. Forty in all were built, and though more or less popular engines, they were credited with being rather sluggish on the northern grades of the line.

In May, 1901, the first of an enlarged class of a 4-cylinder compounds appeared, No. 1941, " Alfred the Great." The leading dimensions of the " Jubilees " and the " Alfred the Greats " are as follows :—

	" *Jubilee.*"	" *Alfred the Great.*"
Cylinders, 2 H.P.	15 ins. × 24 ins.	16 ins × 24 ins.
,, 2 L.P.	20½ ins. × 24 ins.	20½ ins. × 24 ins.
Wheels	7 ft. 1 in. dia.	7 ft. 1 in. dia.
Weight, Engine	54 tons 8 cwts.	57 tons 12 cwts.
,, Tender	26 ,, 12 ,,	26 ,, 12 ,,

Forty of each class were built.

They represent the last type of express passenger engines to be built by Mr. F. W. Webb, who retired in 1903, after being in office 32 years. During this memorable period the second, third and fourth thousand locomotives were turned out of Crewe. On the retirement of this G.O.M. of locomotive designers, Mr. Whale occupied the vacated position, and he speedily set about to undo his predecessor's work, rapidly *scrapping* the 3-cylinder compounds and rebuilding the 4-cylinder " Alfred the Greats " with an additional valve gear to the outside H.P. cylinders, which is said to have greatly improved their efficiency. At this period double heading was in almost constant use on the line, and so Mr. Whale designed a type of engine to remedy this state of affairs, and accordingly, in March, 1904, the first of the new engines, No. 513 " Precursor," a 4-4-0 2-cylinder simple, appeared. The engine created a sensation at the time, the dimensions being far more generous than those usually given to locomotives of that period and are appended :—

Cylinders, 19 ins. × 26 ins.
Coupled wheels, 6 ft. 9 ins.
Weight of engine, 59 tons 15 cwts.
Engine and tender, 90 tons 15 cwts.

The locomotive was an enormous success, and 130 in all were built. A trial with " Precursor " on a train of 471 tons, complete with engine and tender, gave a speed of 67 miles per hour. Probably no class of locomotive has done so much to revolutionise railway working as the " Precursors," and many excellent performances have been credited to them. As the " Precursors " needed a pilot on the northern sections of the line, Mr. Whale brought out another class of engine, in order to do away with this. The first bore the name and number of Mr. Webb's first 3-cylinder compound, No. 66, " Experiment." It was a 6-coupled bogie engine with :—

2 cylinders, 19 ins. × 26 ins.
Coupled wheels, 6 ft. 3 ins. dia.
Weight of engine, 65 tons 15 cwts.
Engine and tender, 102 tons 15 cwts.

Although successful engines they never aspired to the fame of the "Precursors," and, curiously enough, despite their 6-coupled and smaller 6 ft. 3 in. wheels they were said to have been less satisfactory on the very sections of steep gradients for which they were specially designed. Ninety in all were built, and, together with the 130 "Precursors," are all at work at the present time.

In February, 1909, Mr. Whale resigned, and was succeeded by Mr. C. J. Bowen-Cooke, who was Running Department superintendent of the southern section. In 1910 Mr. Bowen-Cooke turned out No. 2663, "George V," the first of a class of 130 engines which earned a fame throughout the world unsurpassed by that of any other class of engine. "George V." was virtually a superheated "Precursor," with certain modifications in the shape of straight-topped coupled wheel splashers, an extended smokebox, and a small wheeled bogie. It is on record that one of these extraordinary locomotives once hauled a train of 357 tons from London to Crewe, 158 miles, in 156 mins 30 secs., and many other equally wonderful efforts have been recorded with them.

Superheating having met with such marvellous success, Mr. Bowen-Cooke decided to apply it to a 6-coupled engine, and accordingly No. 819, "Prince of Wales" appeared, which bore a relation to Mr. Whale's "Experiments" similar to that of the "George V." to the "Precursors." They were fitted with Schmidt superheaters, and proved a great success. Nothing of the brilliancy of the "George V." has ever come to the author's knowledge respecting them, but these dour, determined-looking engines, with their sternly simple outlines and small coupled wheels have been the engines on which the North Western have long relied for all classes of heavy passenger work, and during the war they were much used on troop trains, fast goods, and even mineral traffic. There seems to be little locomotive work of which they are incapable, and the class is, at the present time, being perpetuated to the extent of some 150 engines, which record speaks for itself. The author has recorded some fine runs behind engines of this class.

In 1913 Mr. Bowen-Cook turned out his *magnum opus*, the 4-cylinder simple No. 2,222, "Sir Gilbert Claughton." The engine is interesting in many ways in that it was the first of a regular class of 4-cylinder simple engines for the line, and that Walschaert's valve gear was employed for the first time.

The principal dimensions are as follows :—

Cylinders (4), 16 ins. × 26 ins. (15¾ ins. later batches).
Coupled wheels, 6 ft. 9 ins. dia.
Weight with tender, 117 tons.

Some 70 engines were built, and the author believes that a further order for another batch has been placed with Crewe recently. As in the "Prince of Wales" class, later batches bore no names. Conflicting opinions of the capabilities of the "Claughtons" have come to the author's ears in several years of acquaintance with their work and with the North Western line, but in sorting them out it seems that, though a success, in so far as they were fairly economical and had a light repair bill, they did not fulfil all expectations, and rumour has it that the driving axleboxes ran hot rather more frequently than was desirable. They were not favourites with the drivers early on, owing perhaps to their unorthodox valve gear, but their fine work gained them many friends, and the following, being a run logged by the author and a friend, will show what they are capable of :—

1 P.M. DOWN "SCOTSMAN."

Engine 2,411. Load, 475 tons full.

		H. M. S.	*Speeds m.p.h.*
Euston	dep.	1 0 0	36, 45.
Willesden	arr.	1 11 41	40·9.
,, ...	dep.	1 14 27	
Sudbury	pass	1 19 35	47.
Harrow...	,,	1 24 21	42·8, 50.
Pinner	,,	1 27 0	
Watford	,,	1 32 18	50·5, 50.
Berkhamsted	,,	1 46 0	
Tring	,,	1 51 37	47·3, 50, 52·9, 60.
Leighton	,,	2 0 28	62, 64·2, 64·2.
Bletchley, ...	,,	2 6 7	60, 52·9, 60, 60.
Wolverton	,,	2 13 3	64·2, 60, 60.
Road	,,	2 22 1	56, 60, 45, 50.
Weedon	,,	2 28 30	Check, 1½ mins.
Welton	,,	2 42 35	
Kilsby	,,	2 46 13	62, 69·2-60.
Rugby	arr.	2 51 27	

An engine of this class, "Patriot," commemorates the fallen of the L.N.W.R. by a plate bearing the inscription :—

"IN MEMORY OF THE FALLEN
L.N.W.R. EMPLOYEES.
1914–1917."

A notable point in the design of these famous engines is the fact that the bogie centre is a considerable distance in advance of the chimney centre in contrast to the usual practice, but enhancing the appearance of the engine. This arrangement is made owing to the fact that all four cylinders drive the leading coupled axle, instead of being divided between the first and second pairs, as is generally the case. Theoretically the divided drive is supposed to have an advantage in that the power is more evenly distributed, but the "Claughtons" have, to use the vernacular, "put paid" to this theory.

This concludes a brief resumé of the more important classes of express passenger locomotives which have done duty for the North Western, as no new type has appeared since the "Claughtons." Reference must, however, be made to "Prospero," a 4-6-0 "Experiment," which Mr. Bowen-Cooke experimentally fitted with 4 high-pressure cylinders and a spreading smokebox, presumably in order to test the efficiency of the 4-cylinder simple before launching out into the "Claughtons."

Another of Mr. Cooke's conversions was that of the 4-cylinder compound "Renown," of the Jubilee class into a 2-cylinder simple with 17½ ins. × 24 ins. cylinders inside. Other engines of both the "Jubilee" and "Alfred the Great" classes have been, and are being converted into "Renowns." Thus are all traces of the hand of Mr. F. W. Webb being slowly eradicated from the locomotive stock of the line for which he did so much.

APPENDIX.

SUMMARY OF EXISTING ENGINES.

			Cylinders.	*Wheels.*
			ins. ins.	ft. in.
4-6-0	"Claughton"	(4)	15¾ × 26	6 9
4-6-0	"Prince of Wales"	(2)	20½ × 26	6 3
4-4-0	"George V."	(2)	20½ × 26	6 9
4-6-0	"Experiment"	(2)	19 × 26	6 9
4-4-0	"Precursor"	(2)	19 × 26	6 9
4-4-0	"Renown" ex. ("Jubilee")	(2)	18½ × 24	7 1
4-4-0	"Alfred the Great"	H.P.(2) L.P.(2)	16 × 24 20½ × 24	7 1
4-4-0	"Jubilee"	H.P.(2) L.P.(2)	15 × 24 20½ × 24	7 1
2-4-0	"Precedent"		17 × 24	6 9
2-4-0	"Samson"		17 × 24	6 0
2-2-2	"Cornwall"		17½ × 24	8 6

The following runs were all recorded at different times by the author. Concerning the two down runs, it will be noted that about 1½ mins. were gained in the case of No. 1, the train being piloted as far as Willesden, as is usual with the "Scotsman" when over 400 tons. A maximum speed of 75 miles per hour was recorded at Wolverton, and had it not been for the severe P.W. check at Weedon an even better performance might have been recorded. The extremely loose war-time schedule detracts much merit from the run. In No. 2, as we were piloted throughout and with a lighter load, the run lost much of its interest, the engines contriving to kill time most of the way. The run was remarkable for a poor ascent of the Camden Bank as compared with run No. 1.

L.N.W.R.—Euston to Rugby.

No. of run ...	1.		2.	
Train ...	1 p.m.		1 p.m.	
Engine No. ...	2,411*.		2,416†.	
Engine Type	" Claughton."		" Claughton."	
Load empty ...	435.		409.	
Load, full ...	460.		440.	
	H. M. S.	*Speed m.p.h.*	H. M. S.	*Speed m.p.h.*
Euston dep,	1 0 0		1 0 0	
Chalk Farm ...	1 2 25		1 4 15	
Willesden arr.	1 10 22		1 11 16	
,, dep.	1 15 2		1 15 20	34·5.
Sudbury pass	1 20 27	52·9, 45, 43	1 20 15	
Harrow ,,	1 25 22	45	1 25 0	
Pinner ,,	1 27 56	60	1 27 33	50.
Bushey ,,	1 31 35		1 31 0	47·3, 50.
Watford ,,	1 13 10	47, 47	1 32 45	50, 56, 60. 52.
Boxmoor ,,	1 41 41	45	1 40 30	52·9, 54.
B'khamsted ,,	1 46 12	45, 45	1 45 40	50, 47·3, 50.
Tring ,,	1 51 13	50·6, 56·5	1 49 30	55, 52·5, 54.
Cheddington,,	1 55 50	69, 75	1 54 20	60, 60, 64, 64.
Leighton ,,	—	69, 63, 69	1 58 12	60, 69·2
Bletchley ,,	2 4 50	62, 69	2 4 18	60, 64·2, 60, 66.
Wolverton ,,	2 8 58	75	2 9 48	56·5.
Castlethorpe,,	2 12 13	56	2 12 5	56, 50, 47, 48.
Rhode ,,	2 17 54	50	2 18 22	53, 56.
Blisworth ,,	2 21 28	60	2 21 55	56, 62. Check.
Weedon ,,	2 31 5	Check 3¾ mins.	2 29 15	25, 50, 50, 50.
Welton ,,	2 38 20		2 36 27	47·3, 50, 52·9.
Kiloby ,,	2 42 2	50, 56, 60, 64		52, 53, 42.
Rugby arr.	2 48 35		2 46 0	

* Pilot No. 1,981 " Precursor " Tank to Willesden.

† Pilot " Puck," 2-4-0, throughout.

L.N.W.R.—Rugby to Euston.

No. of Run ...	1.		2.	
Train ...	12·18 p.m. ex. Rugby		†9·38 ex. Rugby. Mon., Oct. 6th.	
Engine No.	* 310, " Achilles "		" New Zealand."	
Engine Type	4-4-0, " Precursor "		4-4-0. Sister " George V."	
Load, empty	—		280 tons.	
,, full	—		300 tons.	
	H. M. S.		H. M. S.	
Rugby dep.	12 22 0		9 38 0	
Rilsby Pass	12 30 50			Dead Stand.
Welton ,,	12 42 0			,,
Weedon ,,			10 2 30	
Blisworth ,,	12 50 45		10 12 0	
Rhode ,,	12 54 15	Check	10 18 20	
Castlethorpe,,	12 59 50		10 24 0	
Wolverton ,,	1 2 5		10 26 5	
Bletchley ,,	1 9 10		A10 32 20	
			D10 43 30	
Leighton ,,	1 12 3		10 53 10	Stand 47 secs.
Cheddington,,	1 17 5		11 3 30	Check.
Tring ,,	1 28 50		11 11 15	
Berkham d. ,,	1 33 40		11 16 5	
Watford ,,	1 37 25		11 28 15	
Bushey ,,	1 47 0		11 30 0	

Pinner	Pass	1 50 9		11 33 0
Harrow	,,	1 52 27		11 35 3
Sudbury	,,	1 56 0	Check	11 38 55
Willesden	,,	2 1 0	Severe check	A11 43 45
				D11 46 45
Chalk Farm	,,	2 6 30		—
Euston	arr.	2 13 25		11 58 35

* Superheater " Precursor."

† Strike running times.

A gain of 4 mins. was recorded.

With regard to the two up runs, No. 1, on the 12.18 express Rugby, was an extremely ordinary performance behind a superheated " Precursor." Three severe checks spoiled all hope of an early arrival, 3¼ mins. being lost.

Run No. 2 is exceptionally interesting in that it was recorded on the day immediately following the conclusion of the railway strike, and normal conditions were far from existing. Two hours and twenty minutes certainly sounds remarkable in the 20th century for a distance of 82 miles, but several dead stands were made to ascertain the lie of the land, the train being run under practically strike conditions. There was of course no schedule. It was unfortunate that maximum and minimum speeds were unobtainable on the up runs owing to the author being alone in each case. It is unfortunate that the author has had no experience of the running of other classes of locomotives, and therefore no first-hand details of coal and fuel consumption can be given. The annexed table shows, however, full technical details of compound and simple passenger and goods locomotives of different companies, the table being obtained from C. Allen's " Modern Locomotives."

LOCOMOTIVE TESTS.

	L.S.W.R.	*L. & Y.R.*		*M.R.*	*L.N.W.R.*
Engine Class	Express	Simple	Comp.	Express	Comp.
,, Type	4-4-0	0-8-0	0-8-0	4-2-2	4-4-0
Dia of driving wheels ...	7 ft. 1 in.	4ft. 6in.	4ft. 6in.	7ft. 9in.	7 ft. 1in.
Dia of cylinders	19 in.	20 in.	(2)15½in. (2)22in.	19½in.	(2)15in. (2)10½in.
Stroke	26 in.	26 in.	26 in.	26 in.	24 in.
Boiler pressure in lb. per sq. in.	167·5	178	180	—	200
Grate area in sq. ft. ...	18·14	23·05	23·05	—	20·5
Coal burnt in lb. per sq. ft. of grate area per hour...	62·54	111·5	74·3	—	20·5
Coal per I.H.P. per hour	4·31 lb.	3·7 lb.	3·1 lb.	2·9 lb.	—
Water evaporated per lb. of coal	9·23 lb.	—	—	—	7·8 lb.
Steam consumption in lb. I.H.P. per hour ...	—	23·3	18·0	—	—
Weight of train in tons ...	—	583	585	—	329¼
Average drawbar pull ...	—	4·37	3·79	—	5·25
Average speed in M.P.H.	—	21·9	23·3	—	50
Average I.H.P.	490·6	701	546	400	—
Coal consumption in lb. per mile	—	—	—	—	43·7

The chief deduction to be drawn from the last table is the economy of the compound over the simple, an economy which, however, has been found to be not worth the extra cost and complexity of the locomotive. The coal burnt per sq. ft. of grate area will be seen to be considerably more in the case of the L.& Y. mineral engine with simple expansion than in the 4-cylinder compound.

During tests on the L.N.W.R. to discover the relative consumptions of long shallow fire boxes as fitted to the 6-coupled "Experiments" with the shorter deeper pattern of the "Precursors," the following results were obtained :—

Engine.	*Mileage.*	*Consumption.* Tons.	cwts.	*Average Consumption per mile.* Lbs.
"Precursor" ...	34,348	882¼	0	57·53
"Experiment" ...	34,013	793	8	52·25

This clearly demonstrated the greater economy of the shallow fireboxes, but, like most other things, it has its disadvantages, chief of which is that the shallow firebox is far more difficult to stoke, and consequently it is harder to get the best out of the engine.

Lately the London & North Western have been experimenting with an oil-burning apparatus fitted to a "Precursor," but, unfortunately, the author has no details of the performances of the engine so fitted.

Monday, June 12, 1922.

T. J. GUERITTE, B.Sc. (Paris), M.Soc.Ing.Civ. (France), F.S.E.,
PRESIDENT, IN THE CHAIR.

THE PHYSICAL PROPERTIES OF CLAY-MUD.

By Dr. HERBERT CHATLEY, D.Sc.(Engineering),
Assoc.M.Inst. C.E., M.Inst.C.E.I., A.Inst.P.

Mud is an important material. Life probably arose from it, and certainly depends on it now. Almost the whole surface of the Earth consists of nothing but compressed mud. What is mud ? It is disintegrated rock mineral, loosened by mechanical and chemical action due to rain, sun and vegetation, and washed down by running water, pulverized into silt, settled by gravity and finally reformed into a soft rather sticky paste. It inclines towards the chemical composition of "kaolinite," which is produced from the decomposition of the mineral "felspar," but may vary widely, and is not necessarily of any definite chemical species.

CHARACTERISTICS OF MUD.

A careful examination of mud shows that it has three special features :—

(1) A granulated structure of varying degrees of fineness.

(2) A semi-permanent water content which gives it peculiar mechanical properties.

(3) A certain small reserve of chemical potential which under certain conditions will cause it to change in various ways.

Ackermann's recent work on the subject of clay (Society of Engineers of London Transactions, 1919, 1920, 1921) is very important.

GRANULATION.

The granulated character may be observed by various methods. A small quantity of mud smeared on to a glass slip and examined under a microscope shows, under magnification of say 100 diameters, a number of crystalline particles, mostly about one-tenth of a millimetre ($\frac{1}{250}$ inch) in diameter, with a few smaller particles. It has even been proposed in America to define clay or silt (the basis of mud) as material capable of passing a 200 to the inch mesh screen, or as composed of particles less than 0·005 mm. in diameter (Meyer's *Hydrology*). If a small quantity (say 1 gramme) of mud is shaken up with water (say 100cc.) and allowed to settle it will be found that a large proportion (say 50%) settles to the bottom in a tall cylinder (say

20 centimetres high) in a minute or so, and most of the remainder settles in an hour or so, leaving a brownish cloud which settles in about a day, leaving an opalescent cloud which settles in about a week, leaving clear water. Given the height of the water column it is easy to calculate from Stokes' rule what the diameters are.

Stokes' rule for slowly descending particles in water is approximately :—

(At 15° C.)

$$v = 8100\ d^2, \text{ or } d = \frac{\sqrt{v}}{90} \text{ approximately}$$

where v is the velocity of descent in centimetres per second and d is the diameter in centimetres. (At 50° C. the descent is twice as rapid owing to decreased viscosity). Thus, if we say that the various stages in a column of water 20 centimetres high occur in the following times, the diameters of the particles are as given :—

	Time.	*V (cm. per sec.).*	*d in cm.*
A. First deposit ...	1 minute = 60 secs.	0·33	0·0065
B. Second deposit ...	1 hour = 3,600 ,,	0·005	0·0008
C. Brown cloud ...	24 hours = 86,400 ,,	0·00023	0·0002
D. Opalescent cloud	7 days = 604,800 ,,	0·00003	0·00006

Since the limit of visibility with 100 diameters magnification is about 0.0002 cm., A and B include all the particles visible with such a power. The C class particles are visible with higher powers (up to, say, 2,000 diameters), but the D class can only just be glimpsed. By the method of "ultramicroscopy" (intense sideward focussed illumination against a dark background) such and even finer particles are evidenced by small "diffraction" halos. Particles of the C and D class and the still finer invisible particles are termed "colloidal," and play a very important part in the plasticity of the mud. This "colloidal" matter can be obtained in appreciable quantities by mixing a large quantity of mud and water, settling it for say one day, siphoning off the top water very carefully and settling that for a week. If the surface water from this is now siphoned off as much as possible, and the remainder allowed to evaporate, a jelly-like sediment will be found which will, like gum, dry to a horny consistency, and is what has recently been termed "ultra-clay." Great care must be taken to avoid any acidity, alkalinity, bacterial action or other disturbing factor in the water or the particles will simply coagulate into a powder somewhat similar to the coarser particles. This fine stuff has various peculiar properties. The particles are so small that their *minimum mutual cohesive forces are comparable with their individual weight* and consequently they can and will stick together. They also have great affinity for water and other substances. This mutual cohesion may, perhaps, be due to a shell of adsorbed or condensed water round each particle, such shells tending to coalesce round two adjacent particles " soldering " the two together. The colloidal content can, in fact, be determined by observing to what extent the particles will "adsorb" certain organic dyes, *i.e.*, how far a solution of dye can be cleared by the colloid.

The plasticity of mud depends principally on the proportion of colloidal particles, but the size of the larger particles also enters into the question since this controls the total magnitude of the surfaces to be stuck together. For example, if the principal particles are $\frac{1}{10}$ millimetre in diameter ($\frac{1}{100}$ centimetre) and are roughly cubical, the surface of each is ·0006 square centimetre. Each weighs nearly ·000003 gramme, so that in one gramme of such grains there are over 300,000 particles, and the total surface is about 180 square centimetres. If the principal particles are $\frac{1}{100}$ millimetre (·001 cm.) in diameter the surface of each is ·000006 sq. cm. Each weighs about ·000000003 gramme, so that in one gramme of such grains there are over 300,000,000, and the total surface is about 1,800 square centimetres. Thus the *total surface* of all the grains *varies inversely* as the mean diameter of the individual grain and for colloidal grains (·0001 centimetre diameter and smaller) the surface amounts to 18,000 sqare centimetres or more per gramme, rising in particles of molecular size (·0000001 centimetre or less) to 18,000,000 square centimetres (1,800 square metres) or more per gramme !

WATER CONTENT.

Next as to the water content. Experiment with broken stone, sand, etc., shows that with ordinary contact about 50 per cent. by volume is " void," *i.e.*, air space or, in mud, water space. The viscosity of mud rises rapidly when the water content is less than 75% by volume.* With equal spherical particles in the closest arrangement (rhombic dodecahedral packing) the interstitial volume would be about 44%. Owing to the varying sizes of the particles, closer packing is possible than with equal particles, even as little as about twenty-five per cent. of water by volume being possible. The following relations between volume and weight are of interest.

If one cubic centimetre of mud weigh s grammes and contain a fractional *volume* w c.c. of water, the volume of the solid particle is $(1-w)$, and if the specific gravity of the solid material is r, then—

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* Frühling and other drag suction dredger experience.

$$s = w + r\ (1\text{-}w)$$

$$\text{or}\quad s = r - w\ (r\text{-}1)\ \textit{grammes}\ ;\ w = \frac{r\text{-}s}{r\text{-}1}$$

The fractional weight of water is—

$$\frac{w}{s} = w_1,\ \text{so that}\ w = w_1 s,\ \text{and}\ s = \frac{r}{1 + w_1\,(r\text{-}1)}\ ;\ w_1 = \frac{r\text{-}s}{s(r\text{-}1)}$$

The density of dry mud—

$$s_1 = r\ (1\text{-}w) = s\text{-}w = s - w_1\, s = s\ (1\text{-}w\ ).$$

The water ratio by weight to the weight of solid—

$$w_2 = \frac{w}{s\text{-}w} = \frac{w_1\, s}{r\ (1\text{-}w)} = \frac{w_2\, s}{r\ (1\text{-}w_1 s)} = \frac{r\text{-}s}{r\ (s\text{-}1)}$$

The water ratio by volume to volume of solid—

$$w_3 = \frac{w}{1\text{-}w} = \frac{r\text{-}s}{s\text{-}1}$$

$$\text{whence}\ s = \frac{r + w_3}{1 + w_3}$$

r is generally about 2·75 for the minerals found in mud. w for soft mud cannot be much less than 0·7 c.c., which makes s = 1·525, and w_1= 0·46 ; w for firmly compacted "dry" mud may be with graded granulation as little as 0·25 c.c., which makes s = 2·342 grammes and w_1 = 0·11 gramme, so that mud varies according to moisture content from about 90 lb. to an extreme value of about 145 lb. per cubic foot. With lighter minerals the specific gravity may be a little less. Clay, rock, shale and slate, when wet, may have s = 2·6 grammes, or even more, but they have no plasticity under moderate stress.

(Table of specific gravities in appendix.)

In the finer forms of clay the absorbed water may be *condensed* round the colloidal particles so that the density rules above are not quite accurate. In other words, some of the water is chemically combined with the clay. This will increase the specific gravity of the finer clays, *e.g.*, alumium hydroxide has about 25% higher density than a mixture of its constituent alumina and water.

The water content may be divided into three classes :—

(1) Free water which can drain away.

(2) Capillary water which is retained by surface tension, but which can evaporate.

(3) Hygroscopically adsorbed, or chemically bound, water, which can be removed only by great heat or chemical action.

The equilibrium of the water in clay is not well understood, but Ackermann's formula for the "pressure of fluidity" (at which the mud will flow at the rate of 1 cm. per sec. or more).

$$p = 0 \cdot 1 \ w_1^{-7} \text{ grammes per sq. cm.}$$

indicates how the water content affects the mechanical properties. Ackermann gives still higher values for low values of w_1. It may be supposed that under pressures greater than this the mud will lose water.

CHEMICAL CONSTITUTION.

The chemical properties of mud are variable and are difficult to distinguish from the physical properties. Plasticity may be dependent to some extent on the chemical composition (*e.g.*, hydrated silicates and aluminates), but even so only in the degree that the chemical composition facilitates physical changes. The differences between lubricants of identical viscosity which have recently been discussed by mechanical engineers and physicists show that chemical constitution may be a real factor in adhesion, but clay is relatively so inert that the physical structure is probably paramount. Mud is changed chemically by mere drying and exposure to the sun (under great heat it dehydrates and becomes a new and solid substance, (" brick " or " biscuit ") with little or no plasticity when powdered and re-wetted.

MECHANICAL PROPERTIES.

Wet mud in mass has various important mechanical properties. It has an appreciable tensile strength of upwards of one atmosphere, *i.e.*, 1 kilo per sq. cm., or 15 lb. per sq. inch, with, say, 15% by weight of water, decreasing to about $\frac{1}{20}$ kilo per sq. cm., with 30% by weight of water. It is elastic under small forces (Young's modulus about 5 kilos per sq. cm. for 30% by weight water content) ; it has a shearing or " frictional " resistance f_s of about 200 or 300 lb. per sq. ft. (100 to 150 grms. per sq. cm.). All these depend on the water content. Approximately under small pressures, $f_s = \frac{0 \cdot 0015.}{w_1^3}$ Mud retains more than 25% by volume of water (= at least 10% by weight) against the gravitational tendency to drain. Mud flows under sufficient pressure (the pressure of fluidity) as a viscous fluid. Its elasticity under small forces is very similar to that of rubber and with 28% moisture content its viscosity is about 10^7 " poises " (dyne-seconds per sq. cm.), which is similar to that of heavy grease and of wax, corresponding to a shear strain of 1 radian per 100 seconds under a shear stress of over 100 grms. per sq. cm. Under these conditions it may be compared to a heavy grease, but with the difference that great pressures alter it by expressing or displacing the water. Under increasing uni-directional stress this " expression " of water is probably not a steadily increasing quantity owing to " dilatation." It may even be negative if the mud is well packed before the pressure is applied, and there is freedom to expand laterally and a constrained boundary.

Clay is not really water-tight, but very great pressure is required to produce appreciable water velocities through the minute pores, so that dykes, etc., allow water to percolate only very slowly, and evaporation may prevent the seepage from being visible. If the surface is dry the surface tension may temporarily arrest the through flow.

Some very important work on the properties of mud has been done by the "Special Committee of the American Society of Civil Engineers to Codify Present Practice on the Bearing Values of Soils for Foundations." A series of progress reports of this committee is appearing in the "Proceedings" of that society. The work is as yet unfinished, but a great deal of information has been collected, and the importance of the colloid content has become more and more apparent. The Committee's method of separating the colloids is by a very high velocity centrifuge (40,000 revolutions per minute, magnifying gravitation upwards of half a million times). In the Committee's last report there is the remark :—

> "This material (colloid) has marked cohesive properties . . . . all indications point to the fact that this material and water constitute elements of extreme importance in the physics of soils."

Again, in defining "clay," it is said :—

> "The grains of these minerals (. . . . silicate of aluminium, iron, the alkalis or the alkaline soils. The hydrated aluminium silicate, kaolin, is the most typical of these. Some feldspar is usually present . . . .) may show crystal faces, but more commonly they are of irregular shapes : upon most of these grains is an enveloping colloid coating. This is mainly of silicate constitution, but may consist partly of organic colloids, of iron, manganese and aluminium hydroxides, and of hydrated silicic acid. Quartz grains which are usually present do not have the colloidal coating, or have it in much less degree. Almost any mineral may be present in clays, and modify the properties somewhat. The combination of granular materials and colloids is in such proportion that when reduced to sufficiently fine size, and properly moistened with a proper quantity of water, plasticity is developed. If the colloid matter is in excess the clay is considered to be very

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NOTE.—According to Ackermann the friction in wet mud varies as the square root of the pressure ; *i.e.*, the friction angle varies inversely as square root of pressure. If so, this change is very important. Crosthwaite finds that the friction varies inversely as the square root of the pressure.

See Appendix in regard to the effect of these ratios on pile design.

plastic, fat or sticky, but if the granular material is in excess it is said to be sandy, weak or non plastic.

" The colloid matters in clay are non-crystalline, hydrated, gelatinous, aluminium silicates, gelatinous silicic and hydrated ferric oxides. Rarely, aluminium hydrate may also be present."

One of the most characteristic artificially prepared colloids is " water-glass " (gelatinous alkaline silicate) which is used for indurating stone or concrete.

Some silt-mud may be regarded as a rather weak clay, being a little too coarse to be regarded as a fat clay.

Another Committee of the Am. Soc. C.E. on " Road Materials " defined *clay* or *silt* as " finely divided earth, generally silicious and aluminous," which will pass a 200 mesh sieve." Coarse material (less than $\frac{1}{10}$ inch) was classed as " sand " (*Proc. Am. Soc. C.E. Dec., 1914*).

That Committee's definition of " clay," Mr. Richardson thought " would hardly meet with the approval of the geologists and soil authorities." Mr. George P. Merrill says that : It (clay) may, perhaps, be defined as an indefinite admixture consisting largely of more or less hydrated aluminous silicates and free silica, with lesser amounts of iron oxides, carbonates of lime, and various silicate minerals which, in a more or less decomposed and fragmental condition, have survived the destructive agencies to which they have been subjected. About the only feature characteristic of all clays is that of plasticity, when wet, and the term is used only with reference to the degree of comminution and plasticity, regardless of mineral nature or chemical composition.

" The well-known geologist, Geikie, defines clay as follows :—

> The decomposition of feldspars and allied minerals gives rise to the formation of hydrous aluminous silicates, which, occurring usually in a state of fine subdivision, are capable of being held in suspension in water, and of being transported to great distances. Those substances, differing much in composition, are embraced under the general term. clay, which may be defined as a white, grey, brown, red or bluish substance, which, when dry, is soft and friable, adheres to the tongue, and, shaken in water, becomes mud. It is evident that a wide range is possible for varieties of this substance.

" In the light of recent conceptions of colloidal chemistry, Mr. Richardson would define clay as follows :—

" Clay is a material resulting from the weathering of rock, usually feldspathic, possessing the property of plasticity when wet, which is due to the presence of disperse colloids. Clay may be residual, *in situ,* where it is formed, or sedimentary and transported by water. In its purer form, it consists of a *hydrated silicate of alumina,* but often contains quartz or other residuals of the rock in which it originates."

The Angle of Friction.

Since the time of Coulomb it has been the custom of engineers to design retaining walls on the basis of a certain "angle of friction" in the back filling which is supposed to be the angle made with the horizontal by the surface of such material, without lateral support, which has had time to acquire stability. In the case of mud the friction angle may vary from 45° down to zero according to the water content. If there are adequate weep-holes in the wall, the water content of the mud cannot rise beyond say 50 per cent. by volume, and in this case the minimum angle of friction likely to occur is about 20°, and it may be much higher. If the work is submerged, or even below the ground water level, friction angles of even less than 10° are possible. Ackermann finds that the co-efficient of friction with constant water content varies inversely as the square root of the compression, but it undoubtedly increases with diminution of the water content. Mud holds a certain equilibrium quantity of water, when there is a free supply of water, dependent on the pressure to which it is subject.

There is a great deal of uncertainty as to the water content of deep lying mud. The present author has shown that with very fine pores it is possible for evaporation to balance invisibly the loss of water pressed upwards to the surface from such mud by its own weight, but on the other hand if the surface is dry the surface tension at the superficial pores can retain the water to an appreciable depth. In these circumstances there may be a difference between mud which is covered with water and that which is usually dry at the surface. Somewhat paradoxically the latter may be internally wetter than the former. A comparison may be made with the case of sponge compressed by a weight. Under water the sponge flattens easily ; out of the water the same weight will not compress it so much, since the surface tension holds the water in.

In this connection something should perhaps be said concerning the fit or "gear" of the grains. If the pressure is not sufficient to crush the grains (which is rarely the case with fine material) the friction may differ very greatly with small displacements. Osborne Reynolds' famous "dilatation" phenomena must be mentioned in this connection. This "dilatation" is a peculiarity of granular assemblages arising from the fact that they have numerous configurations which are stable under uniform stress. If sand is poured slowly into a container and is not shaken it occupies a much greater volume than if it is poured rapidly and is shaken. In the latter case it tends to form the most stable configuration with close gearing and small interstitial volume. If a steady pressure in one direction is applied to this densely packed aggregration it will be distorted laterally. Since the initial configuration is one of maximum density any other must be lighter and consequently have more volume, so that the change will be an *increase* of volume. This paradoxical swelling under pressure is the "dilatation" referred to. It may be seen in wet sea sand, which, when compressed by the foot dries the adjacent sand owing to the drawing of the water by capillary forces into the increased volume. If, on the other hand, the sand is initially a little loose, and is vibrated by the foot, water may be expressed by reason of the closer packing of the sand grains. This phenomenon may occur in mud.

It is usually and rightly the practice to take minimum values of the friction angle, and to neglect cohesion, in designing retaining walls, but it is not always advisable to use this "rule of thumb" method in computing bearing pressures, adhesion, &c., in subsoil structures. For instance, if only constant friction *angles* are assumed, very anomalous results will be obtained in connection with friction piling. Thus, if we say the tangent of the friction angle is 0·2 (corresponding to an angle of about 12°), then the friction at any depth h ft. on 1 sq. ft., if the weight of the soil is 110 lb. per cu. ft., is

$$0{\cdot}2 \times 110 \times h = 22\,h \text{ lb.}$$

or on a pile with a perimeter of p ft. the total is 11 h^2 p lb., giving an average of 11 h lb. per sq. ft.

According to this the friction would average 110 lb. per sq. ft. for a 10 ft. penetration, and 330 lb. per sq. ft. for a 30 ft. penetration; but experiment shows that in clay below the first few feet the *friction* is fairly constant, say 200 lb. per sq. ft. (There is an elastic vertical strain of about 5 mm. (say $\frac{1}{5}$ inch) with ordinary fairly long piles in average Shanghai mud under these conditions). This indicates either that the friction angle decreases with the depth, or that there is a real adhesion additional to the pressure friction. Experiment with sliders shows that such an adhesion actually exists, which in the limit corresponds to the ultimate shear stress of the soil, but when there is only a minute motion it is an elastic shear stress. The latter should be largely independent of the pressure, and this actually appears to be the case.

LATERAL PRESSURE.

The Coulomb-Rankine theory that the lateral "active" unit pressure due to a vertical pressure p is

$$p^1 = p\frac{\sin\,(1 - \Phi)}{\sin\,(1 + \Phi)} = p\tan^2(45^\circ - \frac{\Phi}{2})$$

and the lateral "passive" *resistance* is

$$p^1 = p\frac{sin\ (1 + \Phi)}{sin\ (1 - \Phi)} = p\ tan^2\left(45^\circ + \frac{\Phi}{2}\right)$$

is still widely adopted, but the uncertainty about Φ at any depth and water content makes it of little value. Forsell remarks that if the strains are so small that the reaction is elastic and *no lateral expansion strain* occurs

$$p^1 = \frac{p}{m - 1}$$

where m is the ratio of logitudinal to lateral strain in the case of simple stress, *i.e.*, $\frac{1}{m}$ = Poisson's ratio. If $m = 3$, $p = \frac{p}{2}$ If $m = 2$, as would be the case for *very soft* plastic material, $p^1 = p$, *i.e.*, the pressure is as in a fluid, where $\Phi = o$. As the value of m is even more uncertain than that of Φ, this analysis is not very useful, but perhaps experiment will advance its application. It is suggested by Forsell in this case that the maximum shear stress amounts to

$$f_s = p_2\frac{m - 2}{(m - 1)}$$

and after it passes the elastic limit there is slip and the normal frictional, *i.e.*, ultimate shearing, conditions apply. This elastic hypothesis presupposes no variation of the shearing resistance with pressure, *i.e.*, the material behaves just like a solid.

Information on the variation of adhesion with pressure is very conflicting, largely on account of the ambiguity as to the water content. Certain records show that adhesion increases with pressure from a definite value under no pressure. American experiments with Kentucky ball clay show that the zero pressure adhesion increases with repetition of the loading, but that under a given high pressure the total friction is the same. Ackermann, as mentioned before, considers the coefficient of friction to vary inversely as the square root of the pressure, but the water content and its changes must play a large part.

Plasticity.

The mechanical theory of the nature of plasticity is not very complete, but there are certain principal features :—

(1) There is flow, *i.e.*, irrecoverable displacement.

(2) Two phases may be distinguished :—

A. Semi-permanent deformation which is partially recovered, and is produced slowly under continued stress, disappearing slowly when the latter is removed, and diminishing a little even under constant stress.

B. Plastic flow which is produced at a *constant* rate proportional to the distorting stress, and is permanent.

> This steady flow is the characteristic of a " fluid," and is measured by the reciprocal of the " viscosity." The physical quantity termed " viscosity " (the shearing stress at unit space rate of change of velocity perpendicular to the shearing plant) indicates the limiting stresses.
>
> The ratio of the viscosity to the " modulus of rigidity " is termed the " relaxation time," and is a measure of the time required for unit distortion to take place.

According to Ashley the plasticity of clay is measured by

$$\frac{(\text{Fraction of colloids}) \times (\text{Ratio of contraction when air dried})}{(\text{Total surface area of all particles in unit weight})}$$

Other methods may be employed, analogous to the " hardness " tests and tensile extension and contraction tests used for metals, but no real standard has yet been developed.

The difference between fluids of high viscosity, such as clay, and those of low viscosity, such as water—lies in the stress required to produce flow. In the case of water this is, except for minute quantities, less than the weight of the mass under stress, whereas in the case of clay in moderate quantities it is large, so that if the externally applied stress necessary to produce flow is removed the flow ceases. Powerful surface tensions seem to play a great part in arresting such flow. Modern physics considers that all solids have surface tension, possibly of the order of 10,000 dynes (10 grammes) per centimetre or more.

During flow there is generally little change of volume, but this is not necessarily true of mud, which may change volume by loss or gain of water. It should be remarked that under sufficiently great stresses all materials will flow. Cold metal and rock have been made to flow freely under artificial pressures, and there can be no doubt that some miles down in the crust of the earth the material is practically fluid when it can move at all.

Piling in Clay.

Ackermann holds that fluidity pressures occur in clay under pile points during driving or when loaded until sufficient frictional force is developed. This is not the case in the general mass of the clay, so that the flow, if it does not occur upwards to the surface round the pile, must take place radially and displace water from the general mass. It has not been observed how far such transmitted effect goes, but approximate calculations indicate that drying of this kind extends through a radius several times that of the pile itself. Close piling must either raise the mud surface or very appreciably dry the material between the piles. This, of course, is borne out by experience.

The design of bearing and sheet piles raises numberless questions on the properties of mud, which are very difficult to answer, but it is hoped that this study will help to explain some of the anomalies. *In all cases, if possible, the stresses developed in the clay after the completion of the structure should be elastic and not semi-plastic. This is the main criterion of permanent stability*

APPENDIX.

1. CLASSIFICATION OF SOILS BY FINENESS.

Am. Soc. C.E. Committee on Road Materials.

Gravel—retained on a 10 mesh screen (say more than 2 millimetres).

Sand—Passes 10 mesh : retained on a 200 mesh screen (say more than 1/12 millimetre).

Silt or Clay.—Passes a 200 mesh screen.

Am. Soc. C.E. Committee on Bearing Power of Soils.

Grits	0·5 to 4·0	Millimetres	diameter.
Dust	0·0625 to 0·5	do.	do.
Flour	0·0078 to 0·0625	do.	do.
Powder	0·0019 to 0·0078	do.	do.
Colloids	below 0·0019	do.	do.

U.S. Department of Agriculture.

Fine gravel	1·0 to 2·0	Millimetres	diameter.
Coarse sand	0·5 to 1·0	do.	do.
Medium sand	0·25 to 0·5	do.	do.
Fine sand	0·10 to 0·25	do.	do.
Very fine sand	0·05 to 0·10	do.	do.
Silt	0·005 to 0·05	do.	do.
Clay	0·0 to 0·005	do.	do.

Rough Classification adopted by the Author for Screening Samples.

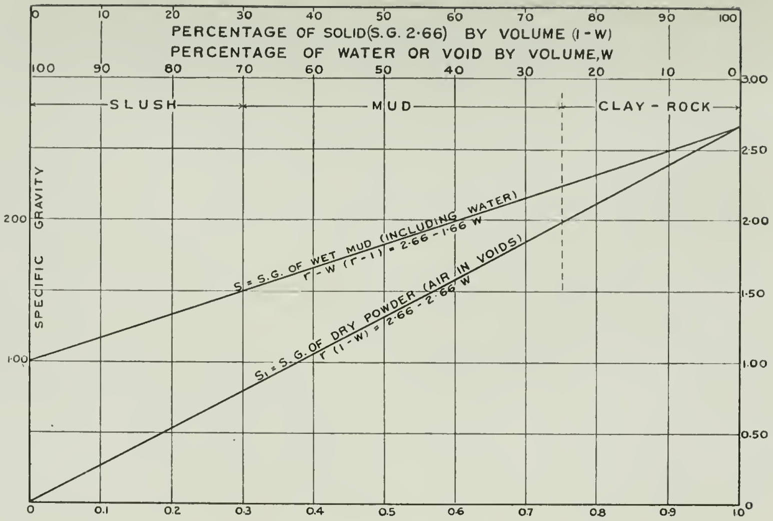
Sand retained on 50 mesh screen, say $\frac{1}{60}$ in. holes = 0·4 mm.

Fine Sand retained on 100 mesh screen, say $\frac{1}{125}$ in. diameter = 0·2 mm.

Silt and Clay passes 100 mesh screen.

2. *Table of the Volumes of Mud corresponding to the various densities of Mud and solid mineral as given below, containing one gramme of solid (volumes expressed in cubic centimetre).*

Density of mud (C.G.S.)	Density of solid mineral (C.G.S.).						
	2·33	2·40	2·50	2·60	2·6	2·70	2·75
1·50	1·14	1·16	1·19	1·23	1·25	1·26	1·27
1·55	1·04	1·06	1·09	1·12	1·14	1·15	1·16
1·60	0·95	0·97	1·00	1·02	1·04	1·05	1·06
1·65	0·88	0·90	0·92	0·94	0·96	0·97	0·98
1·70	0·82	0·83	0·86	0·88	0·89	0·90	0·91
1·75	0·76	0·78	0·80	0·82	0·83	0·84	0·85
1·80	0·71	0·73	0·75	0·77	0·78	0·79	0·795
1·85	0·67	0·69	0·71	0·72	0·74	0·745	0·75
1·90	0·63	0·65	0·67	0·68	0·69	0·70	0·705
1·95	0·60	0·61	0·63	0·65	0·66	0·665	0·67
2·00	0·57	0·58	0·60	0·62	0·625	0·63	0·635
2·25	0·46	0·47	0·48	0·49	0·495	0·50	0·515
2·50			0·40	0·41	0·415	0·42	0·425
2·75							0·36


PERCENTAGE OF SOLID(S.G. 2·66) BY VOLUME (1 - W)
0
10
20
30
40
50
60
70
80
90
100
PERCENTAGE OF WATER OR VOID BY VOLUME, W
100
90
80
70
60
50
40
30
20
10
0
SLUSH
MUD
CLAY - ROCK
SPECIFIC GRAVITY
2·00
1·00
3.00
2·50
2·00
1·50
1.00
0.50
0
S = S.G. OF WET MUD (INCLUDING WATER)
r - W (r - 1) = 2·66 - 1·66 W
S₁ = S.G. OF DRY POWDER (AIR IN VOIDS)
r (1 - W) = 2·66 - 2·66 W
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

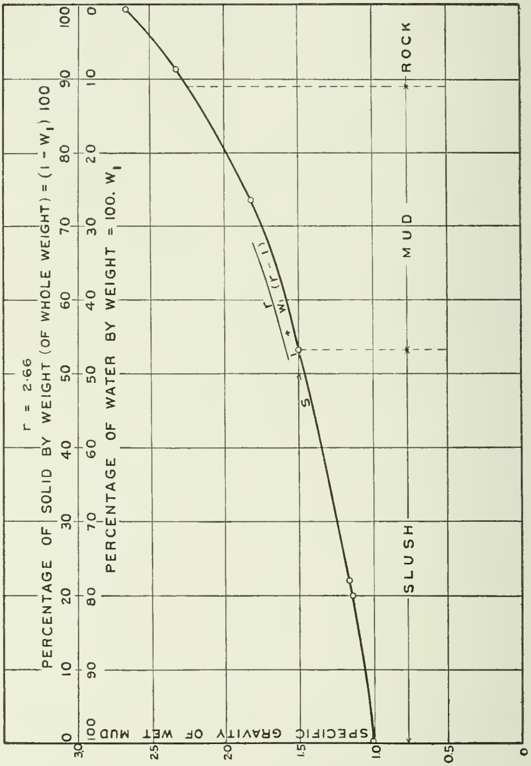

r = 2·66
PERCENTAGE OF SOLID BY WEIGHT (OF WHOLE WEIGHT) = $(1 - W_1)\,100$
0 10 20 30 40 50 60 70 80 90 100
PERCENTAGE OF WATER BY WEIGHT = $100.\,W_1$
100 90 80 70 60 50 40 30 20 10 0
SPECIFIC GRAVITY OF WET MUD
3.0 2.5 2.0 1.5 1.0 0.5 0
$S = \frac{r}{1 + w_1(r-1)}$
ROCK
MUD
SLUSH

Table of the Volumes of Water in 1 cc. of mud with the densities of mud and solid mineral as given (C.G.S. Units).

Density of mud	Density of Mineral.						
	2·33	2·40	2·50	2·60	2·6	2·70	2·75
1·50	0·623	0·642	0·666	0·688	0·701	0·706	0·715
1·55	0·587	0·607	0·633	0·657	0·672	0·678	0·687
1·60	0·548	0·571	0·600	0·624	0·642	0·648	0.657
1·65	0·511	0·535	0·566	0·593	0·611	0·618	0·629
1·70	0·474	0·500	0·533	0·562	0·580	0·587	0.600
1·75	0·436	0·464	0·500	0·531	0·550	0·557	0·571
1·80	0·398	0·428	0·466	0·500	0·521	0·529	0·542
1·90	0·323	0·357	0·400	0·437	0·461	0·470	0·485
1·95	0·286	0·321	0·366	0·406	0·431	0·441	0·457
2·00	0·248	0·286	0·333	0·375	0·401	0·412	0·428
2·25	0·061	0·107	0·167	0·218	0·251	0·264	0·294
2·50			0	0·062	0·102	0·117	0·147
2·75							0

3 ECONOMIC ARRANGEMENT OF SQUARE PILES ACCORDING TO A GIVEN VALUE OF PILE FRICTION.

Load per unit area of ground = W
Number of piles per unit area of ground = n
Side of pile = d
Penetration = h
Exposed length = l
Friction surface of piles = $4nhd$
Mean friction per unit of friction surface = f_m

$$4 f_m nhd = \text{W} \quad \ldots\ldots\ldots \quad (1)$$

Volume of piles per unit area of ground—

$$\text{V} = n\ (l+h)d^2 \ldots\ldots\ldots\ldots (2)$$

Let $f_n = f_o - ch$, where f_o = the friction per unit area when $h = o$ and c = constant ; $c_m = \frac{c}{2}$:

$$\text{Then } f_m = \frac{(f_o - ch) + f_o}{2} = f_o - \frac{c}{2} \cdot h = \text{f}_o - c_m \cdot h \quad \ldots\ldots\ldots\ldots (3)$$

From (1) and (3)

$$n = \frac{W}{4f_m \cdot hd} = \frac{W}{4hd\ (f_o - c_m h)}$$

Substituting in (2)

$$V = \frac{W\ (l + h)\ d}{4h\ (f_o - c_m h)} \qquad \text{.......................................} (4)$$

This is a minimum (or maximum) when $\frac{dV}{dh} = 0$

$$\frac{dV}{dh} = \frac{4h\ (f_o - c_m h)\ Wd - Wd\ (l + h)\ (4f_o - 8\ ch_m)}{[4h\ (f_o - c_m h)]^2}$$

This is equal to zero when the numerator is zero, or the denominator is equal to ∞. (The latter corresponds to the maximum.)

Hence $4h\ (f_o - c_m h = (1 + h)\ (4f_o - 8c_m h)$

Expanding

$$4hf_o - 4c_m h^2 = 5f_o l + 4f_o h - 8c_m hl - 8c_m h^2$$

$$\therefore\ 4c_m h^2 + 8c_m \cdot l \cdot h = 4f_o l$$

$$\therefore\ h^2 + 2lh = \frac{f_o l}{c_m}$$

$$\therefore\ h = \sqrt{\frac{f_o l}{c_m} + l^2} - l$$

is the condition for minimum pile volume.

Example :—If $f_o = 300$ lb./ft.² : $c_m = 5$; $l = 20$ ft.

then $h = \sqrt{1200 + 400} - 20 = 20$ ft.

Formulæ for Minimum Volume for Piling according to several types of variation of friction with depth.

CROSTHWAITE'S RULE.

$$f \propto \frac{1}{\sqrt{h}}$$

$$V = \frac{W\ (l + \ d^2 h)}{f_m\ 4dh}$$

V_{min} when $h = l$.

ACKERMANN'S RULE.

$$f \propto \sqrt{h}$$

gives $h = -3l$ (unreal)

actually there is no definite minimum.

RANKINE'S RULE.

$$f \propto h$$

and again gives no definite minimum.

CHATLEY'S RULE

$$f = f_o - c_m . h$$

gives $h = -l + \sqrt{\frac{f_o\, l}{c_m} + l^2}$

All these, except Ackermann's, disregard the vertical pressure on the end surface of the pile.

Monday, June 12, 1922.

T. J. GUERITTE, B.Sc. (Paris), M.Soc.Ing.Civ. (France), F.S.E.,
PRESIDENT IN THE CHAIR.

THE PHYSICAL PROPERTIES OF CLAY.

[FOURTH PAPER.]

AND A SUPPLEMENT ON PILE-SET GAUGES.

By A. S. E. ACKERMANN, B.Sc. (Engineering), A.C.G.I., M.Cons.E., A.M.I.C.E.

The results of 24 experiments (Nos. 259 to 282 inclusive) are recorded in this paper.

The second grant from the Dixon Fund, made by the Senate of the University of London in 1920, is still not exhausted, so it has not been necessary to apply for a third grant. This is largely due to nearly all the apparatus having been home-made, and the author hereby records with pleasure the fact that Mr. Hal Gutteridge, A.M.I.Mech.E., has materially helped him with the making and testing of the pile-set gauges herein described. As most of the time has been occupied with the making and testing of these gauges, the few other experiments will be described first.

Exp. (259), April 9, 1921.—It was considered of interest to determine whether any other material than clay has a " pressure of fluidity " as defined and recorded in the previous three papers. [To save reference to those papers, it may be stated that when a disc resting on clay is gradually loaded it sinks into the clay a certain distance in a certain time for each addition to the load ; and when the stress is sufficiently great, depending principally on the percentage of water in the clay, the disc sinks much more rapidly, and without any further additional load. The stress necessary to cause this effect is called the pressure of fluidity.*] Lead was selected for the purpose. The " disc " was a wrought iron punch 53 mm. long, the shank 6·5 mm. diam. except for the last 4 mm. Three of these formed a tapered portion enlarging from 6·5 mm. to 7·5 mm., and the final mm. was cylindrical, 7·5 mm. diam. The specimen of cast lead was in the form of a cylinder 45 mm. diam. and 50 mm. high, with the top and bottom ends turned in a lathe. The punch was held in the lower end of a length of steam pipe. Three pins were

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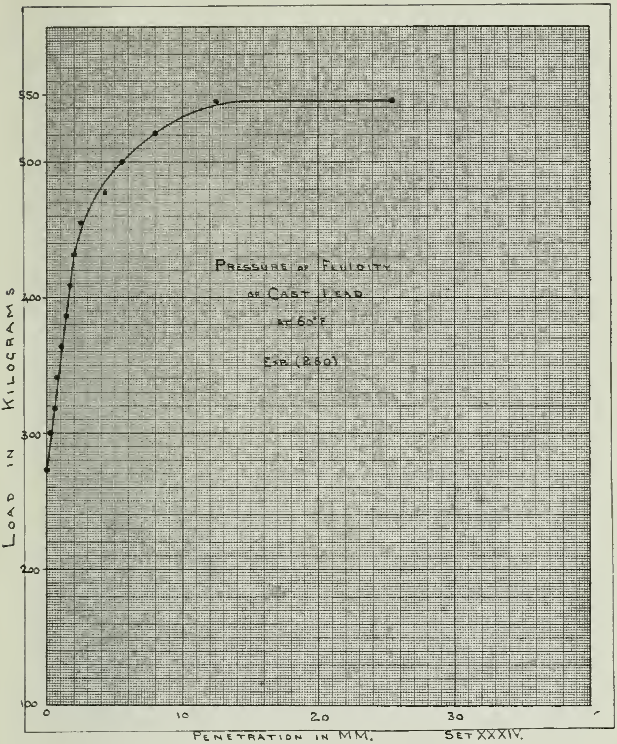
*At p. 21 of the *Progress Report of the Special Committee of the American Society of Civil Engineers to Codify Present Practice on the Bearing Value of Soils for Foundations*, published Feb.,1921, in Vol. XLVII., No. 2, of the Proceedings of the American Society of Civil Engineers, it will be found that the Committee has adopted the author's disc method of testing the resistance of clay, etc., published March, 1919. Their larger apparatus, described in their Report of August, 1920, is on the same principle.

screwed into the lower end, and these supported a circular table having a central hole through which the vertical steam pipe passed. The top end of the pipe was loosely guided by a hole in a fixed piece of wood. The table was gradually loaded until the total load was 98,506 grams. This was left on from 9.15 p.m. on April 9, 1921, to 5.0 p.m. the next day without any penetration being recorded. At that time the total load was increased to 125,056 grams. The weights of the neighbourhood and the loading capacity of the apparatus were then exhausted, so the load was removed. The top surface of the lead was only just marked by the punch, though the stress had been 283 kilos. per sq. cm. (= 1·8 tons per sq. in.), and Unwin, at p. 96 of his *Strength of Materials*, gives the compressive strength of lead as 0·75 ton per sq. in., and at p. 419 as "from $1\frac{1}{2}$ to 3 tons per sq. in."

Exp. (*260*), *April 23, 1921.*—Mr. Percy J. Neate, M.I.Mech.E., having a 3-ton testing machine in his private workshop, kindly offered his assistance and the use of his testing machine for making the experiment, which were gladly accepted. The same punch and specimen of lead were used as for Exp. (259). The specimen was placed on a steel plate in the machine. The results are recorded in the curve forming Set XXXIV., which clearly exhibits the characteristics of the corresponding curves for clay. Thus lead also has a pressure of fluidity, and its value is $\frac{545}{0\cdot 445} = 1{,}233$ kilos. per sq. cm. (=7·83 tons per sq. in.). The temperature of the workshop was 60° F. The punch was easily pulled out by hand, being merely a tight fit, so that the lead had not closed in behind the " disc."

It was shown at I, p. 200, that after the pressure of fluidity had been reached, the work done in kilo-cms. per c.c. of clay displaced is *numerically* equal to the pressure of fluidity in kilos. per sq. cm. Hence the work done in displacing the lead was 1,233 kilo-cms. per c.c. after its pressure of fluidity had been reached.

The author suggests that, in the case of clay, the work done per c.c. displaced might be used as a measure of its plasticity. Zschokke has suggested that the product of the tensile strength and the percentage elongation of a cylinder of clay 66 mm. long by 30 mm. diam., is a measure of the plasticity of clay. This product is Tetmajer's Value Figure multiplied by 100, for Tetmajer's Value Figure is the product of the tensile strength and the elongation per unit length ; but while the tensile strength and elongation are fairly easily to determine accurately in the case of the usual metals, the author does not consider it easy to determine accurately either the tensile strength or the elongation of clay. On the other hand, the determination of the pressure of fluidity may be done both easily and accurately.



When the load of 545 kilos. was on the punch it was obvious from the steady fall of the end of the lever of the testing machine that the pressure of fluidity had been reached, and eight sets of readings were taken to determine the rate of penetration. The end of the testing machine lever was allowed to fall about 30 mm. during each set of readings. The lever was then raised in the usual manner by taking up the penetration of the specimen by means of the screw for the purpose, and the next set of readings was then taken. The lever ratio for these readings was 19·5 to 1. Thus a fall of the end of the lever of 32 mm. represented a penetration by the punch of $\frac{32}{19 \cdot 5} = 1 \cdot 643$ mm.

Time in seconds.	Penetration in mm.	Speed of penetration in mm. per sec.
68	0·923	0·01465
121	1·795	0·01485
114	1·282	0·01124
172	1·643	0·00954
187	1·795	0·00959
141	1·488	0·01055
174	1·640	0·00943
205	1·540	0·00750
1,182	12·106	0·01025

The modification of Stoke's Law discussed at pp. 103-4 of Paper III. is—

$$\eta = \frac{(\text{load in grams on disc})\ g}{6\pi r v}$$

In Exp. (260) load = 545,000 grams.
$r = 0{\cdot}375$ cm.
$v = 0{\cdot}01025$ mm. per sec. $= 0{\cdot}001025$ cm. per sec.

η, the viscosity of lead at 60° F.,

$$= \frac{545{,}000 \times 981}{6 \times 3{\cdot}1416 \times 0{\cdot}375 \times 0{\cdot}001025} = 7{\cdot}37 \times 10^{10} \text{dyne-secs.per sq.cm.}$$

Exp. (*261*), *April 23, 1921.*—For purposes of comparison with ordinary compression tests of lead, a specimen was cut from the lead used for Exp. (260) and turned into a cylinder 10 mm. diam. and 20 mm. high. This was placed between two polished steel plates, and gradually loaded until in 50 mins. the total load was 273 kilos. The total compression was then 6·5 mm. The original horizontal area of the specimen was 0·7854 sq. cm., and the final mean area (*i.e.*, allowing for the increase due to the compression) was 1·165 sq. cms. Hence the final stress was $\frac{273}{1{\cdot}165} = 234{\cdot}5$ kilos. per sq. cm. (=1·49 tons per sq. in.), compared with 1·64 tons per sq. in. given by Trautwine for a similar test.

As the specimen failed partly by shear, Exp. (262) was made with another piece of the same lead on April 30, 1921. This specimen was 1·25 cms. diam. and 2·45 cms. high. The load was gradually applied in 25 mins., the final load being 454 kilos., and the total compression was then 7·5 mm. The original area was 1·23 sq. cms., the final area 1·77 sq. cms., and the final stress $\frac{454}{1{\cdot}77} = 256{\cdot}5$ kilos. per sq. cm. (= 1·63 tons per sq. in.).

Exp. (280), December 18, 1921.—This experiment was devised for the purpose of determining the load necessary to crush a model cliff of clay, and the curve which the originally vertical plane of the cliff would take as a result of the crushing. The clay was confined in a tin having the form of a parallelopiped with one vertical side and the top end omitted. In plan the tin measured 165 × 150 mm., and its height was 295 mm. The open side measured 150 mm. wide × 295 mm. high. A wooden piston 165 × 150 mm. × 12·5 mm. thick loosely fitted the tin, which was filled with well rammed clay, the surplus being sliced from the open side by a taut wire. The top side of the piston was flush with the top edge of the tin, so that the initial height of the clay in the tin was $295–12{\cdot}5 = 282{\cdot}5$ mm. On the piston was placed a smaller slab of wood 12·5 mm. thick; on the middle of this a column of wood 52 × 78 mm. in horizontal section, and 145 mm. high. On top of this column was placed a comparatively large wooden board or table, on which were placed the weights forming the load. The piston, column, and table were purposely placed loose on one another, so that the weights had to be distributed about the table in such a manner that their mass centre was vertically above the centre of the piston.

Opposite and parallel to the vertical face of clay, and 153 mm. from it, was fixed a thin piece of three-ply wood, 130 mm. wide by 280 mm. high, called hereinafter the guide board. In it were two vertical columns of 7 holes, each about 2 mm. diam. The holes in each column were 40 mm. vertically apart, and the horizontal distance between the columns was 65 mm. The bottom hole of each column was 14 mm. above the level of the bottom of the tin. The two columns of holes in the guide board were so placed laterally in regard to the face of clay that one column was immediately opposite the vertical centre line of the face of clay. The other column was thus 65 mm. to the left of the centre line, and therefore opposite a vertical line on the face of the clay, which was $\left(\frac{150}{2} - 65 =\right)$ 10mm. from the left side of the tin. This left-hand column was called A, and the column opposite the centre line of the clay was called B.

Fourteen knitting needles were passed through the 14 holes in the guide board, the ends towards the clay being fitted with wooden hemispherical buttons, each 13 mm. diam., the spherical surface of each being pressed about half-way into the face of the clay, care being taken to keep the needles horizontal and in their respective two vertical planes. When so arranged the other ends of the needles projected about 60 mm. beyond the back of the guide board. Each of these projecting lengths was carefully measured before any load was placed on the clay; then a load was put on, and some time after the projecting lengths were again measured. The increase of each length was the amount the corresponding part of the clay face had bulged forward. The complete set of readings was as follows :—

Time p.m.	Load on Piston in grams.	Col.	Numbers of the Needles.						
			(1) Top N'dle	(2)	(3)	(4)	(5)	(6)	(7)
				Readings of Needle-projections in mm.					
4.40	0	A	63·7	61·6	59·5	61·4	58·4	60·2	60·1
—	—	B	64·6	64·7	62·5	60·0	58·7	62·3	64·2
5.0	27,391	—	—	—	—	—	—	—	—
6.20	27,391	A	66·4	63·7	60·7	62·5	59·2	60·6	60·3
6.30		B	67·8	67·4	64·5	61·6	59·4	62·7	64·3
6.44	51,424	—	—	—	—	—	—	—	—
7. 2	51,424	A	81·6	78·7	73·9	70·4	62·1	61·4	60·5
7.15		B	82·0	83·7	81·8	75·1	65·7	65·7	65·2
7.49	51,424	A	85·0	81·4	79·6	73·1	63·8	62·0	60·7
7.59		B	85·7	86·1	86·9	77·5	68·2	67·1	65·5

Needles Nos. 1 were at the tops of the columns and needles Nos. 7 were at the bottom.

The temperature of the clay was 54° F., and it contained 25·5% of water.

The bracketed times such as $\left.\begin{matrix}6.20\\6.30\end{matrix}\right\}$ mean that it took that period of time to take the set of 14 needle readings. They were taken from the top downwards, the A column being read first, then the B column. Hence A1 was read first and B7 last.

At 7.20 p.m. needles Nos. 1 to 5 in each column had a decided slope, owing to their buttoned ends being low, and between needles 4 and 5 there was an indication that the clay was yielding by shearing.

By 7.25 p.m. the piston had descended 23 mm.

By 7.39 p.m. the piston had moved laterally out of the tin (with the clay) a distance of 19 mm., and the clay immediately under the open side of the piston had come forward about 5 mm. beyond the edge of the piston. At 8.02 p.m. the A front corner of the piston had descended 38 mm., and the corresponding back corner 29 mm., the B front corner 33 mm. and the B back corner 26 mm. The mean total vertical movement of the piston was thus 31·5 mm., and its total forward movement 25 mm. The slope of the two No. 1 needles was estimated to be 20°, and that of the pairs Nos. 2 and 3 was also practically 20°.

The pairs Nos. 4 and 5 sloped less, and less, while pairs Nos. 6 and 7 had practically no slope.

The needles remained in their respective vertical planes as at the start.

There were four vertical cracks in the face of the clay at the end of the experiment, which is remarkable, for this clay, when it contains $25 \cdot 5\%$ of water, is particularly tenacious. By 8.32 p.m. all the load had been removed, and the resulting mean *rise* of the piston was 2 mm., apparently due to the elasticity of the clay; but there was the possibility of this being due to the spring of the three sides of the tin, though the two equal and larger sides were each supported by a central vertical wooden batten.

The plane of shear showed across the face of the clay at a height of 130 mm. from the bottom.

In the final stage it was found that the maximum width of the protruding clay was 166 mm. It had, therefore, expanded 16 mm. laterally.

The maximum load was 51,424 grams, and the area of the piston was 247·5 sq. cms. Hence the maximum compressive stress was 207·5 grams per sq. cm.

PILE-SET GAUGES.

On May 9, 1921, in the course of conversation with Mr. Ernest Latham, A.C.G.I., M.Inst.C.E., he called the author's attention to the problem of recording the set of marine and river piles when they are driven by means of floating pile-drivers. By May 15th the author had designed and made the autographic pile-set gauge now to be described, and it was roughly tested that day on a 5·3 cm. square pine pile 165 cms. long, driven by a sledge hammer wielded by Mr. Gutteridge, without mishap to the instrument! The results of these rough tests (Exps. 263–5) were so promising that a pile-driver was made 3 metres high, with a monkey weighing 33·6 kilos. This was used for the first time on June 11, 1921, in the author's garden, the same pile being driven into virgin London clay. Exps. (266*a* to *e*) were made. (*a*) and (*b*) not having the spring pawls on the suspended weight in use, and the results were:—

	Actual set in mm.	Set recorded on the curve in mm.
(266*a*) ...	20	20
(266*b*) ...	22	20

Principle of the Autographic Pile-set Gauge.

The principle of this gauge is as follows :—When a weight is suspended from a bracket by a long helical spring, the spring extends until it exerts an upward force on the weight exactly equal to the earth-pull (weight) on the weight. If, then, the bracket be suddenly moved down say 20 mm. the upward pull of the spring on the weight will be reduced to a small extent, and the initial accelerative force, causing the weight to move down, will be the difference between the then upward force of the spring on the weight, and the earth-pull down on the weight. This difference will be exactly equal to the momentary decrease of the upward pull of the spring due to the bracket having moved down. The mean accelerative force will only be half the initial, and the downward movement of the weight will be *very much less* than what it would be if it were free to fall by the action of gravity, as it would be if, for example, instead of being suspended by a helical spring, it were suspended by an inextensible string. Consequently, when this weight is suspended by the long spring, and the bracket is suddenly moved down (as it is when it is fixed to a pile struck by a monkey), the weight remains practically fixed in space for a fraction (say a tenth) of a second. This affords the fixed point in space from which to measure the set of the pile.

The following results were obtained with the spring used for the gauge :—

Weight of suspended weight	710 grams
Length of helical spring when extended by the above weight	273 mm.
Length of helical spring when extended by a weight of 642 grams...	254 mm.
Difference	19 mm.

Thus if the bracket supporting the top end of the spring be moved down 19 mm., the upward pull of the spring on the weight is reduced from 710 to 642 grams, and the *mean* force causing the weight to descend is $\frac{710-642}{2} = 34$ grams $= 34 \times 981$ dynes.

Hence from the relation, force = mass × acceleration we have $34 \times 981 = 710a$, therefore $a = 47$ cms. per sec. instead of 981 c.s.s. for a freely falling weight.

Thus the acceleration of the weight has been reduced to $\frac{47}{981} = \frac{1}{20{\cdot}9}$ of that due to gravity by the action of the spring.

Description of the Autographic Pile-Set Gauge.

Fig. 1.

The method of utilising the principle just described is as follows :—

A bracket or hook is fixed to the pile, and to this is attached the top end of a long helical spring. To the lower end of this suspension spring is attached the suspended weight which slides freely on two vertical guide rods. A suitable pencil holder is fixed to the suspended weight. Behind the suspended weight is a platen of thin three-ply wood sliding horizontally in a grooved frame fixed to the pile, the plane of the platen being vertical. To the sliding platen is attached a piece of paper on which the pencil autographically draws a time-penetration curve, time being abscissæ, and penetration ordinates. To the left-hand end of the platen is attached a light helical spring, which is extended when the platen is pulled by hand to the right-hand end of its frame. The right-hand end of the platen is provided with a small hook, which engages with another hook fixed to the right-hand end of the frame. One end of a Bowden wire engages with the hook on the platen in such a manner that when the Bowden wire is pulled it releases the platen, which then moves rapidly to the left. At the other end of the Bowden wire is a small lever, which may be placed at any desired height above the top of the pile, and in such a position that the monkey in falling strikes the lever and thus releases the platen. The blow of the monkey causes the pile to penetrate the soil. Thus the top end of the suspension spring moves vertically down an amount equal to the set of the pile. This *reduces* the upward pull of the helical spring on the suspended weight, but owing to the inertia of the weight and remaining upward pull of the spring, the suspended weight (and thus also the pencil) remains *practically* at rest for a fraction of a second during which the blow of the monkey causes the pile to penetrate, and the curve is autographically drawn during this fraction of a second.

If the apparatus is required to record large penetrations (say of 5 cms. or more), then, in place of the hook or bracket, the top end of the suspension spring is attached to an "eye" at the bottom of a long weight having saw teeth pointing downwards attached on opposite sides of it. This weight is supported by two spring pawls, which are fixed to a bracket fixed to the pile, and engage with the saw teeth on the sides of the weight. When the pile is struck by the monkey the bracket and the spring pawls move down, but the weight by its inertia remains behind, though its tendency to move down is much greater than that of the spring-suspended weight, because, not only is the earth-pull acting on it, but the top end of the helical

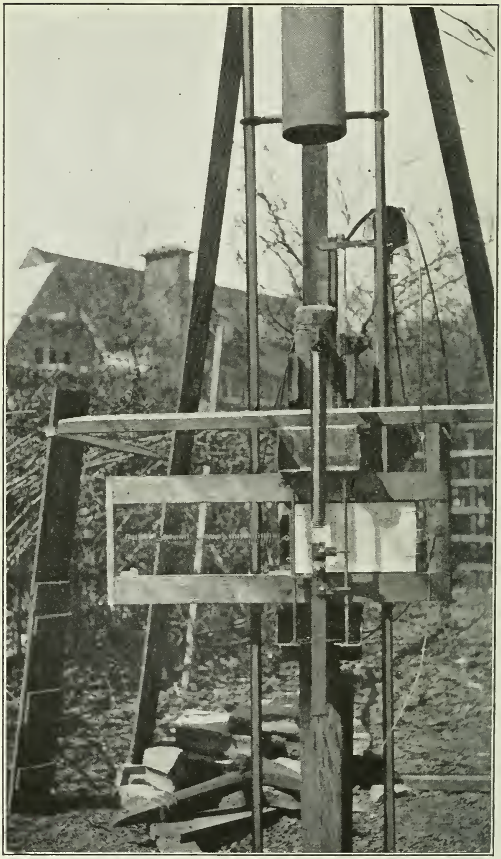


FIG. 1.—AUTOGRAPHIC PILE-SET GAUGE.

Part of the monkey is seen at the top. Between it and the head of the pile is the lever of the gear for releasing the platen carrying the white curve paper. Resting horizontally on the top of the base-board of the instrument is a metre rule, with its centre at the centre of the pile.

spring is also pulling it down. For this reason this top weight *does* move down more in the same short time than the spring-suspended weight. But for all this the top end of the helical spring moves down much less than it otherwise would do, and consequently the motion of the suspended weight is reduced to *practically* nothing during the period of the motion of the pile.

From the foregoing description it will be seen that (the pencil being the fixed point) the horizontal motion (abscissæ=time) of the curve-paper is produced by the light horizontal helical spring, while the vertical movement of the curve-paper (ordinates=the set) is produced by the vertical moment of the pile carrying down with it the grooved horizontal frame in which the platen carrying the curve-paper slides horizontally. The weight of the autographic gauge (without the suspended weight, which, of course, is not subject to the blow of the monkey) is 4·25 kilos. The weight of the suspended weight is 973 grams.

At first, the spring-suspended weight, carrying the pencil, was fitted with two spring pawls, one on each side of it, pointing down, each of which engaged with a vertical saw-toothrack fixed to the two brackets which support the two round guide-rods of the suspended weight. It was not proposed to use these spring pawls when drawing an autographic curve, but it was thought that a direct reading instrument would be simpler and sufficient in many cases.

In experimenting with the autographic gauge the only difficulty met with was that of keeping the pencil on the curve paper. The severe jar of the blow of the monkey produced a lateral flick of the small pile, which jerked the pencil momentarily off the paper, giving a dotted instead of a continuous line. (Fig. 2.)

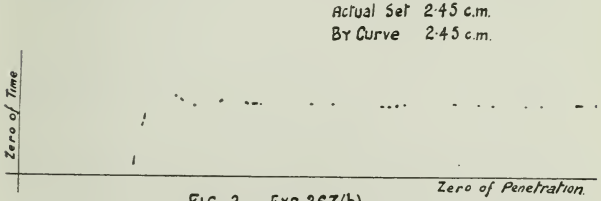


FIG. 2. EXP. 267(b).

This is of little importance except at the beginning of the curve while the pile is in vertical motion. A new pencil gear was made and tried on June 25, 1921, Exps. (267*a–f*) were made, *b*, *c*, and *d* not having the suspension weight pawls in use. The next day, after reducing some of the play of the moving parts of the gauge, Exps. (268*a*, *b* and *c*) were made.

During the morning of June 28, 1921, a number of engineers were invited by telephone to witness some tests of the autographic pile-set gauge in the author's garden in the afternoon, and in spite of the shortness of the invitation seven were good enough to attend. Experiments (269 *a* and *b*), and (270 *a b*, and *c*) were made in the presence of the visitors, who, in fact, took most of the readings as a check.

TABLE I.

Summary of Results obtained with the Autographic Pile-set Gauge on a 53 mm. Square Pine Pile, about 70 cms. in Clay *in situ*.

Date.	No. of Experiment.	Actual Set of Pile in cms.	Set recorded by the Autographic Curves in cms.	Remarks.
1921.				
June 25th ...	267 (*b*)	2·45	2·45	
,, ...	267 (*c*)	2·70	2·55	Max. error – 5·6%
,, ...	267 (*d*)	2·46	2·40	
,, ...	267 (*e*)	[2·53	2·70]	Rejected : trip gear failed.
,, ...	267 (*f*)	2·43	2·35	
June 26th ...	268 (*a*)	2·36	2·36	
,, ...	268 (*b*)	2·25	2·25	
,, ...	268 (*c*)	2·20	2·15	
June 28th ...	269 (*a*)	2·00	2·00	
,, ...	269 (*b*)	1·90	1·90	
Totals ...	—	20·75	20·41	Mean error, – 1·64%.
Total error ...	—	—	– 0·34	
June 28th ...	270 (*a*)	3·80	3·60	
,, ...	270 (*b*)	4·00	3·65	
,, ...	270 (*c*)	4·00	3·80	
Totals ...	—	11·80	11·05	Mean error, – 6·35%.
Total error ...	—	—	– 0·75	

It will be noticed that the sets of Exps. (270 *a*, *b*, and *c*) were double most of the others. This was because the drop of the monkey was then 135 cms., or nearly double what it had ever been before. On the first of these heavy blows, the top end of the suspension spring jumped off the hook, and the weight fell by gravity without any restraining action due to the spring. The resulting curve (Fig. 3) is most instructive, and brings out clearly (on the principle of salt being " that which makes bread nasty when there isn't any in it " !) the extremely important action of the spring. By certain calculations it has been estimated that the whole of each curve is drawn in $\frac{1}{10}$ second. In this time, when the suspension spring is in use and the acceleration is 47 cms. per sec., per sec. as has been shown, the weight falls 2·5 mm., and, on measuring the curves, this is found to be the fall, thus showing that the $\frac{1}{10}$ sec. is very probably correct. On the other hand, when the weight fell freely, the measured fall was 50 mm., which is almost exactly what calculation shows it would be in $\frac{1}{10}$ sec. When the top end of the spring had been wired on to its hook, Exps. (270*b* and *c*) were made, and Fig. 4 shows how the pencil then kept up. The error of the gauge for the three bigger sets was naturally larger than for the smaller ones, because the duration of the motion of the pile was much longer, and therefore gave more time for the weight to fall. In practice it is probably only rarely that sets of more than 20 mm. each need to be recorded. In such cases the gauge could be calibrated, and its errors for large sets could be corrected. When making further experiments with the spring pawls in use, simultaneously with the autographic apparatus, it was frequently found that the set recorded by the pawls was considerably more (*e.g.*, 24·3 mm. compared with 17·0 mm.) than that recorded by the autographic curve, which latter was usually correct. At the time no

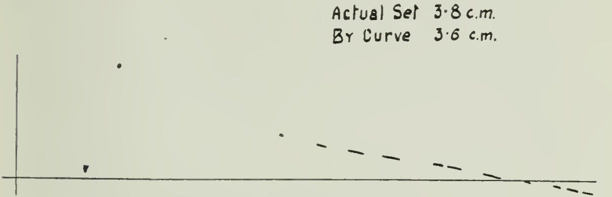


Fig 3. Exp. 270(a)

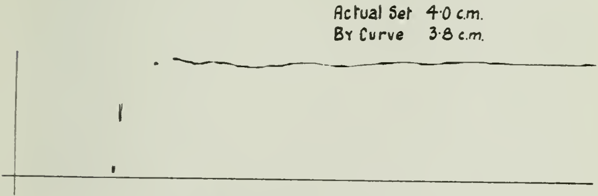


Fig 4. Exp. 270(c)

certain explanation of this could be found. It is more remarkable when it is remembered that the pawls were rigidly attached to the same weight as the pencil, and yet the latter recorded a smaller set than the pawls! The explanation will be given later.

On July 16, 1921, a 75 mm. square pine pile, 2·44 metres long, was started, the 53 mm. one being too far in the ground to be any more use. The weight of the moving part of the pencil holder had been reduced from 20 to 10 grams in order to reduce its inertia in the hope that its spring would then keep it on the paper better, this being still the only difficulty, for the author wishes it to be realised that the autographic pile-set gauge gave excellent results, [Exps. (267 *a & b*), p. 7], on its first trial on a monkey-driven pile, and that no alteration of it has been made since it was first constructed, beyond reducing the play of some of the parts. Contrary to the usual experience, it was expected there would be less difficulty in dealing with a full-sized pile and monkey than with model ones, the reason being that the small pile was not quite vertical, and, being so small, its lateral " flick " was troublesome. This expectation proved correct, as will be recorded later.

Exps. (272 *a* to *l*) and (273 *a* to *e*) were made on the 75 mm. pile, the chief result being that the recoil of the pile and/or the clay was repeatedly and clearly recorded by the curves. With a drop of 44 cms. of the monkey the recoil was about 10 mm., and the set 2 mm. On pouring about 1½ gallons of dirty water round the foot of the pile (there had been a severe drought for months) the recoil was still about 10 mm., but the set increased to 4 mm. On several occasions it was found that during the period between the experiments the pile had been extruded 2 mm. Fig. 5, Exp. (273*e*) is an autographic curve taken on the 75 mm. pile, which clearly records the elastic recoil, the drop of the monkey was 35 cms. The total (momentary) compression was 9 mm., the recoil 5 mm., and hence the set 4 mm. The set was also directly measured and found to be 4 mm.

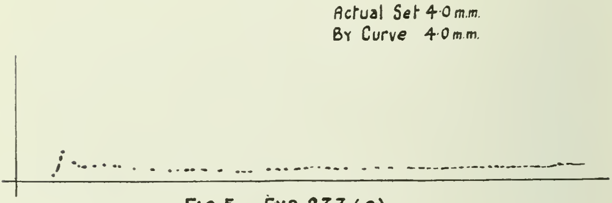


FIG 5. EXP. 273(e)

With regard to the amount of time-lead given to the platen (*i.e.*, the period of time between the monkey striking the releasing gear lever and the top of the pile) in Exp. (270*a*), Fig. 4, the drop of the monkey was 135 cms., and the releasing gear lever was 17 cms. above the top of the pile. Hence by calculation it is found the time-lead was 0·044 second. During this period the platen moved 22mm., starting from rest.

It has been shown that the whole of each autographic curve is drawn in about $\frac{1}{10}$ sec. This can be checked by means of the curve drawn in Exp. (270*a*) when the suspended weight accidentally fell freely. The latter and larger part of the curve is a straight line inclined 10° to the horizontal. Let t_1 be the time measured from the moment the monkey strikes the trip gear to some point P on the curve. Let t_2 be the time measured to the same point P from the moment the monkey struck the pile. Then the time-lead is $t' = t_1 - t_2$, and t' can be calculated from the drop of the monkey and the height of the trip lever above the top of the pile.

Let v_h be the horizontal speed of the platen when the pencil is at some point P, and let v be the vertical speed of the weight and pencil (falling freely) also when the pencil is at P. Then $v = gt_2$ and $v_h = at_1$ where a is the acceleration of the platen, which is assumed to be constant.

$$\text{Then } \frac{v}{v_h} = \tan a = \frac{gt_2}{at_1} = \frac{g(t_1 - t')}{at_1} \qquad \ldots\ldots\ldots(1)$$

The portion of the curve under consideration being straight means that the ratio $\frac{g}{a}$ = const., hence we may write $g = ca$, where c is some constant and equation (1) becomes—

$$\frac{v}{v_h} = c\,\frac{t_1 - t'}{t_1} = c\,\frac{t_1 - 0{\cdot}044.}{t_1} \quad \text{But} \frac{v}{v_h} = tan\ a = 0{\cdot}1763.$$

Therefore—

$c\,\frac{t_1 - 0{\cdot}044}{t_1} = 0{\cdot}1763$, and assuming $t_1 = 0{\cdot}094$ sec., then $c\,\frac{{\cdot}05}{{\cdot}094} = 0{\cdot}1763$, therefore $c = 0{\cdot}331$.

Now, if $t_1 = 0{\cdot}094$, and t' being $0{\cdot}044$, then $t_2 = 0{\cdot}05$, and $v = gt_2 = 981 \times 0{\cdot}05 = 49$ cms. per sec. ; and from equation (1) $v = 0{\cdot}1763\ v_h$, therefore $49 = 0{\cdot}1763\ v_h$, therefore $v_h = 278$ cms. per sec.

The *mean* speed of the platen is half this, say 140 cms. sec., and this speed maintained for $\frac{1}{10}$ sec. = 14 cms., which is roughly the length of each curve. Hence, again, the assumption that t_1

about = $\frac{1}{10}$ sec. proves to be reasonable. The speeds of the platen could obviously be determined in the usual manner by means of a large vibrating tuning fork.

AUTOGRAPHIC PILE-SET CURVES TAKEN AT TEDDINGTON LOCK.

Owing to the courtesy and technical interest in the gauge of Mr. G. J. Griffiths, M.Inst.C.E., the chief engineer of Thames Conservancy, the author was able to test the autographic pile-set gauge on a pitch-pine pile driven by a hand-winch pile-driver in the Thames at Teddington Lock, on November 22, 1921.

The pile was 15¼ × 15¾ ins. × 33 ft. long.

The author was told by the foreman in charge that on starting this pile it sank a foot into the ground below the water by its own weight, and that it was about 7 ft. in the ground when half the experiments were made. By measurement it was found that the water was 4 ft. deep by the pile, it being low tide, and the pile being down-stream from the lock. The length of the pile above the surface of the water was 22 ft. The centre line of the gauge when fixed to the pile was 13 ft. from the top of the pile. The pile-driver was erected on a floating barge, and the weight of the monkey was said to be 1 ton, and looked it.

Before testing the autographic gauge, a very simple, direct-reading, spring-pawl, form of the gauge (the lower instrument of the two in Fig. 6) was tested, and the first blow of the monkey threw a flood of light on the mysterious fact, previously recorded, of the spring pawl nearly always recording a larger set than was true. The elastic recoil of the pile threw the weight up about 50 mm., and thus spoiled the true reading, which was probably correctly on record for the first 1/200 sec. ! The gauge was then tried without any suspending spring, the weight being supported by the spring pawls, but again the weight was thrown up as before. The drop of the monkey for these tests was about 2 ft., and the set ¼ in.

The autographic gauge was then fixed on the pile. The actual sets were read by means of a pointer formed of a triangular piece of zinc sheet nailed to an old pile actually touching the new pile being driven. It was not an entirely satisfactory method. The gauge was screwed to the pile by means of four ordinary wood screws, 3 ins. long and ¼ in. diam. The position of the gauge on the pile was marked at the start, and after 24 blows of the monkey, the drop varying from 2 to 6 ft., it was found that gauge had not shifted on the pile so much as the thickness of a line.

Speaking generally, the curves obtained were similar to those obtained on the 2 in. pile, but they were better, as the pencil

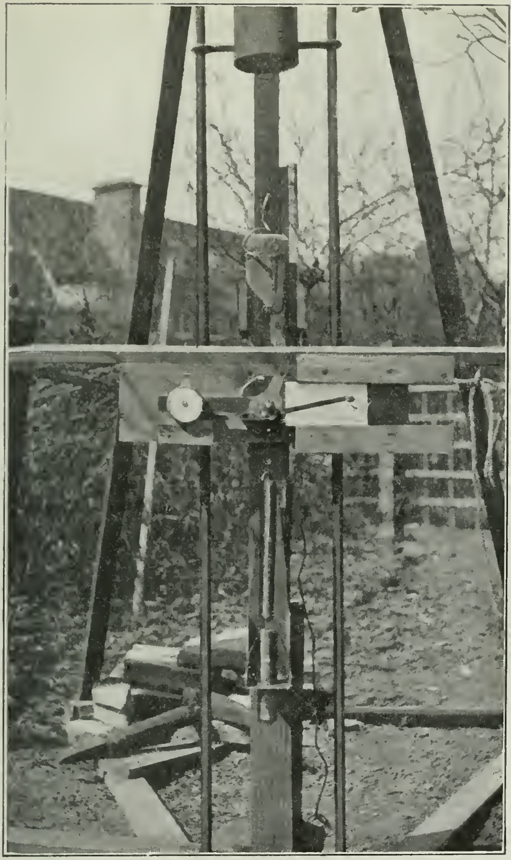


Fig. 6.

Placed at the head of the pile (so as to be seen in the illustration) is the releasing hook for the monkey. It consists of two L-shaped hooks hinged at the bottom on the left. On pulling the string horizontally the front L slides the suspension eye of the monkey off the hook. A metre rule rests horizontally on the base board of the simple form of autographic gauge. Below this is the simpler of the two direct reading gauges. The two spring pawls fixed to the bottom of the bracket are seen engaged with the tops of the two racks forming part of the suspended weight. The weight has a scale marked downwards on its lower portion, the zero being where the weight passes through the bracket.

kept on the paper better, due to there being less lateral vibration of the pile, and the elastic recoil of the pile was larger owing to the greater length (20 ft.) of pile subject to comparison, and measurement, by the gauge. Two of the curves obtained from this pile are shown in Figs. 7 and 8.

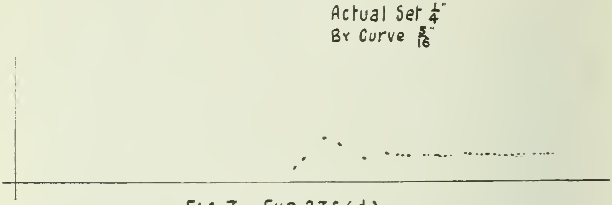


FIG.7 EXP. 275(d)

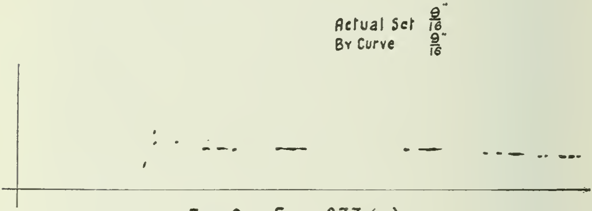


FIG 8. EXP. 277(c)

The following are some of the tabulated results :—

TABLE II.

Experiment.	Drop of Monkey.	Lead for Trip Gear.	Actual Set in 16ths of an inch.	Set recorded by the Curve in 16ths of an inch.	Elastic Recoil in 16ths of an inch.
	Ft. in.	In.			
274 (*a*) ...	4 0	8	10	10	6
,, (*b*) ...	4 2	8	11	10	6
,, (*c*) ...	3 10	8	10	10	4
,, (*d*) ...	3 4	8	9	9	5
,, (*e*) ...	4 3	8	12	12	4
,, (*f*) ...	4 3	8	12	15	?
,, (*g*) ...	4 3	8	14	13	?2
,, (*h*) ...	4 8	8	13	14	4
,, (*i*) ...	4 8	11	12	13	?
,, (*j*) ...	4 9	11	11	11	?
			114	117	

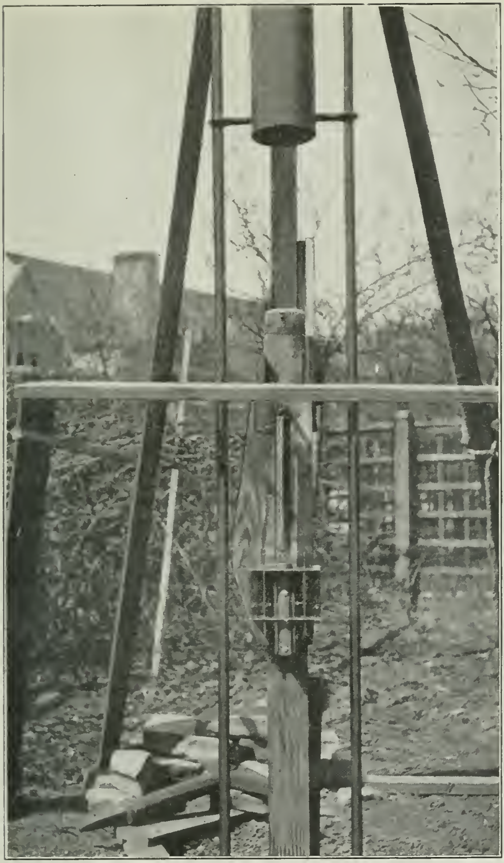


FIG. 9.

Double ratchet form of direct-reading pile-set gauge, for recording both the downward and upward movements of the pile. The suspended weight and its racks are seen in the zero position, and some of the scale on the lower portion of the weight is seen. The two sliders, one on each side of the weight, are also seen, but the two pairs of spring pawls attached to these sliders are not visible, though the bolts and nuts attaching them to the sliders are seen near the bottom of the bracket. The two spring pawls attached to each slider curve upwards and outwards, right and left, from the bolt and nuts. The racks forming the extreme right and left portions of the bracket may be seen, but not their teeth.

Total error of gauge $\frac{3}{16}$ in. on $\frac{114}{16}$ ins. = + 2·6%. From Table II. it is seen that for a drop of the monkey of 4 ft. 3 ins., the elastic recoil was $\frac{1}{4}$ in. This may have been due to the compression of the soil as well as of the pile. Suppose it be assumed that all the elastic compression was due to the pile, then from the data given it is found that the maximum kinetic energy of the monkey was 9,526 ft.-lb. This was all absorbed in producing a movement of one inch. Hence the maximum compressive force on the pile due to the kinetic energy alone of the monkey was R such that $\frac{1}{2}\mathrm{R}\frac{1}{12} = 9526$. Therefore $\mathrm{R} = 229{,}000$ lb. To this must be added the dead weight of the monkey, making the total max. force 231,240 lb. The elastic compression produced by this was $\frac{1}{4}$ in. on a length of 20 ft. of the pile. Therefore e, the compression per unit length, was $\frac{\frac{1}{4}}{240} = \cdot00104$ in. The cross section of the pile was 240 sq. ins., and p, the compressive stress, was $\frac{231{,}240}{240} = 965$ lb. sq. in. Hence as $p = \mathrm{E}\,e$, therefore E, the modulus of elasticity of the pitch-pine of the pile, was 928,000 lb. per sq. in. In another case, a 4 ft. drop produced a total movement of $\frac{13}{16}$ in. and an elastic compression of $\frac{3}{16}$ in. Hence $E = 1{,}435{,}000$ lb. sq. in. The mean of these values is 1,182,500, and *Kemp's Pocket Book* gives 1,225,000 lb. sq. in. Hence, *in this case*, it appears to be a reasonable assumption that practically the whole of the elastic recoil was due to the pile alone.

Another Form of Direct-Reading Pile-set Gauge.

When it was found at Teddington that the recoil of the pile spoilt the reading of the simple gauge, means were devised by which it was thought this would not only be overcome, but that both the max. " compression " and the recoil would be recorded. This was done by providing the gauge with *two* pairs of spring pawls and corresponding saw-tooth racks, as shown in Fig. 9. The inner pawls engaging with the racks on the suspended weight record the maximum " compression," and the outer pawls engaging with the racks attached to the bracket record the elastic recoil. This gauge works admirably when held in one hand and struck with the other, first on top and then underneath, but when tested on the 75 mm. pile both readings were far too large. After some time and further experimenting the cause of this and earlier mysteries was discovered ; the blow of the monkey produces a wave of compression in the helical suspension spring, which rapidly and violently passes down and up the spring, causing the first one pair of pawls to slip some teeth of their racks, and then the other, thus spoiling the initial readings. This was demonstrated experimentally by pulling part of the helical spring down by hand, and letting it go suddenly. This started a similar, though less violent wave, which caused the pawls to slip teeth.

In the case of the autographic gauge, no difficulty has arisen from this cause, because the curve is drawn in about $\frac{1}{10}$ sec., *i.e.*, before there is time for the harm to be done. Similarly, if the blow of the monkey caused the suspended weight of the autographic gauge to oscillate, the time of this oscillation would be in accordance with its natural period. This period, or rather frequency, has been found to be 56 complete oscillations per min., or slightly fewer than 1 per second; hence it is easy to see that in $\frac{1}{10}$ sec. no practical ill-effect could occur from this cause.

A Simpler Form of Autographic Gauge.

This is the upper instrument shown in Fig. 6. It consists of a pivoted lever, with a weight at the end remote from the pivot. This weight is suspended by a long helical spring (not shown in the illustration), the top end of the spring being supported by a bracket fixed to the base-board of the instrument. A thin steel pencil holder, equal in length to the length of the lever, is attached to the lever. The pencil rests on curve paper attached to a platen, which is caused to move horizontally by being pushed by the short arm of the pivoted lever.

The grooved guides of the platen are fixed to the pile. When the monkey strikes the pile, the centre of the suspended weight momentarily forms the fulcrum of the lever. Suppose the set of the pile is 20 mm. then the lever pivot moves down this amount, as it is fixed to the pile. The pencil and weight being at equal distances on opposite sides of the pivot, when the pivot moves down 20 mm. in fixed space, the pencil likewise moves down 40 mm., but the platen also moves down 20 mm.; hence the pencil moves down 20 mm. relatively to the platen and thus records the set. On this very simple gauge being tested, the trouble due to the wave of compression passing down and up the helical spring was again experienced, and the movement of the platen was not sufficient to be satisfactory.. A form of pneumatic spring might be better, as the mass of the wave of air would be much less than that of the spring. This gauge was also tried without any spring, the weight being supported on a block under it, as shown in the illustration. This seemed more promising, and may be successful when the platen is given more motion. Originally this gauge was designed by the author with *two* suspended weights and two levers, one to move the pencil and one to move the platen. The single lever form, suggested by Mr. Gutteridge, was made first, and if it will work it is by far the simpler.

In conclusion the author wishes to call attention to two reports to the Chief Engineer of the Whangpoo Conservancy Board, in connection with the Shanghai Harbour Investigation. The first (officially No. II.) of these is by Dr. Herbert Chatley, D.Sc.(Engineering) Lond., A.M.I.C.E. It is dated July, 1921, and is on *The Physical Properties of the Soil in the Neighbourhood of Shanghai.* In it Dr. Chatley has given ten references to the author's work, and based some calculations on it. The second report (officially No. IV.) is by Mr. Karl Bryhn, another engineering assistant to the Whangpoo Conservancy Board. It is dated May 10, 1921, and is on *Pile Tests.* These were *loading* tests, and are comparable with the author's experiments recorded in his first paper (March, 1919). The piles varied from 16 in. sq. and 59 ft. long to 4 in. sq. and 10 ft. long. Most were timber, some were concrete. It is very gratifying to the author to find that these full-sized tests, as far as they go, and which cost several thousand pounds, completely confirm his small scale work, which cost one shilling ! At least five of the author's important conclusions in regard to piles are confirmed, and in only one is there disagreement.

For convenience the agreement is set out in tabular form.

Agreement of the Author's small-scale experiments (the results of which were published in March, 1909) with the Wangpoo Conservancy Board's similar experiments with full-sized piles (the results of which were published in October, 1921).

The references are to the Wangpoo Report IV. and to the Author's first paper.

Ackermann.	Karl Bryhn for the Whangpoo Conservancy Board.
" The mean value of the friction per unit area on a cylindrical pile usually decreases as the penetration increases."—(I. p. 90.)	" The tests indicated that the resistance per unit area of the pile decreases with the length of the pile."—(E. W. Johnson, p. 3.)
" The author claims that increased penetration (with increased load) was due chiefly to the pressure of fluidity having been reached, and possibly also to the pile having ' rubbed itself free ' in the upper portion that had penetrated."—(I. p. 78.)	" The load and the sinking increase almost in proportion to a certain point, beyond which the sinking rapidly increases with the load." " The adhesion between the clay and the pile may easily be destroyed by rubbing the pile against the clay, as actually happens when driving a pile."—(Karl Bryhn, p. 13.)
" For equal depths, tapered piles support a larger load per unit volume of the pile than piles having parallel sides."—(I. p. 79 (6).)	" The shape of a conic pile should, therefore, probably be better adapted to clayey soil."—(p. 13.)

"Clay has a definite pressure of fluidity, and when this pressure is reached, and maintained, the clay yields indefinitely as a dense viscous fluid."—(I. p. 78 (3).)	"An 'elastic limit' certainly exists, and some curves show clearly conditions corresponding to a 'breaking point,' *i.e.*, deformation without increase of load . . . the sinking increases in a faster ratio than the loan until the 'breaking point' or 'ultimate stress' is reached, where the strength of the mud is exceeded and the mud fails, sinking under constant load."—(p. 14.)
"It is highly probable that the pressure of fluidity was reached (in experiments with model piles made by Mr. P.M.Crosthwaite), but it was not discovered (by Mr. Crosthwaite) because it was masked by the support afforded by the friction on the sides of the piles."—(I. p. 106.)	"The sinking does not cease until the submerged area of the pile becomes large enough to hold the pile on account of the *friction* between the pile and the ground.—(p. 14.)

THE ONLY DISAGREEMENT.

"The mean intensity of friction for the same depth of penetration, on the sides of parallel piles is greater in the case of piles of small cross section than in the case of larger ones."—(I., p. 79 (10).)	"The skin friction seems to increase with the size of the piles."—(p. 27). On this point the author remarks that Mr. Bryhn apparently made no correction for the support afforded by the ends of his piles,* and, if so, such support in the case of a pile of large cross section would naturally be greater than that of one of smaller size.

This agreement between model and full-scale experiments should give engineers more confidence in small-scale work, which obviously is vastly cheaper and quicker, and the conditions can be more thoroughly known and controlled. It is not suggested that model experiments should replace full-scale ones, but they should precede them, so that the results obtained may indicate what to expect from the large-scale work, how it should be carried out, and how difficulties may be overcome or avoided.

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* Dr. Chatley has since told the author the correction was not made.

Discussion.

The **President (Mr. T. J. Gueritte)** said the members were fortunate in that, during his short stay in this country, such an authority on the subject as Dr. Herbert Chatley should have found it possible to give them the privilege of hearing his interesting contribution to a most difficult problem.

His definitions of the physical properties of clay were concise and lucid. The results of the extensive experiments, as set forth in the report to the Whangpoo Conservancy Board, were valuable in themselves, but for the members they offer an even greater interest, inasmuch as they enable them to compare those " full scale " tests with those which Mr. Ackermann had so systematically carried out during the last few years on a small scale.

He remembered that when the first and second papers contributed by Mr. Ackermann came to light, one or two engineers thought that such research work was unlikely to lead to any practical results. Although he did not share all the views held by Mr. Ackermann, when his first paper came out, he considered that engineers were witnessing the forging of the first link of what would become an important chain of evidence, and he thought that the corroboration derived from the Board's full-scale work must be highly pleasing to Mr. Ackermann.

On the whole, and for the conditions studied, he was much in agreement with Mr. Ackermann's conclusions, and might say that as regards the only point of disagreement between his evidence and that of the Board, he felt inclined to agree with Mr. Ackermann.

Clay was a most puzzling material. He confessed that, in order to avoid the inconvenience which might result for a structure from changes in the behaviour of softish clay foundations, such as were known to have occurred occasionally after a lapse of a few years, he was always tempted to reach safer strata, if at all possible. The extra cost of providing piles a few feet longer was generally well worth spending, if one can thereby reach a hard layer. In such cases the part of the load carried by the point of a pile was greatly in excess of that which might be considered as taken up by skin friction on the sides, and the latter was often neglected. He had had experience of cases in which a firm foundation could not be found, and in which skin friction had to be exclusively relied upon.

In a case, in this country, the piles were made 90 ft. long ; in another, abroad, a depth of 120 ft. was reached. In both cases two alternatives had been considered :—

(1) A large number of shorter piles of comparatively small scantling, such as was suggested in the paper.

(2) A smaller number of long piles of large scantling (from 20 ins. to 24 ins. square).

Although the first solution might, theoretically, be considered as most economical, it was found that, for practical reasons, the second alternative would pay better, and it was adopted, the results having been highly satisfactory in both cases.

The apparatus devised by Mr. Ackermann for accurately recording the set of piles driven from a barge should be welcomed both by engineers and contractors, as the difficulty of ascertaining the facts under such conditions was considerable.

Mr. P. M. Crosthwaite, M.Inst.C.E., in opening the discussion, congratulated the authors on their papers, and said that all present were greatly indebted to Mr. Ackermann for continuing the researches he had described in his three previous papers. He was much interested in Mr. Ackermann's experiments on lead for a precisely similar experiment had been made for him by Prof. S. M. Dixon in his large testing machine at the City and Guilds (Engineering) College, which gave a similar result to that described by Mr. Ackermann. It was well known that lead flowed under great pressures, though below a certain limit it behaved as an elastic solid. Otherwise it would not be possible to use it for jointing water pipes, for if it behaved as a true viscous liquid, it would, in time, flow out of the joints. The point he desired to ascertain was at what pressure it began to flow. To determine this it would be necessary to determine what stress it would carry under truly static loads that were given sufficient time for the plunger to come to rest before additional loads were added. It appeared to be practically impossible to carry out this experiment in a testing machine, for, judging from Mr. Crosthwaite's experience with stiff clays, the individual loads might take days to come to rest.

On the last page of his paper Mr. Ackermann suggested that in the paper published by the Institute of Civil Engineers in 1917, Mr. Crosthwaite had missed the fluidity point owing to its being masked by the friction on the sides of the piles. Mr. Crosthwaite had, however, distinctly pointed out that with stiff clays an annular space was formed between the piles and clay so that there could have been no friction. Also, in his later experiments, described in the correspondence on Mr. Ackermann's third paper, Mr. Crosthwaite gave particulars of experiments which showed that fluidity point was only obtained by comparatively quick loading, but that when each load was given time to come to rest no such result was obtained.

Turning to Dr. Chatley's paper, Mr. Crosthwaite was surprised to find he was credited with a rule which stated that the friction varied inversely as the square root of the depth. This was certainly not his rule, and he did not agree with it, for he had assumed that the load was carried by the clay and not by friction between the clay and the sides of the pile. If the rule attributed to him were true, the whole load would be carried by pile friction, and no part of it by the material under the pile.

A somewhat similar rule was given by Dr. Chatley as Rankine's, except that here the friction was said to vary as the depth. Now, so far as Mr. Crosthwaite could understand, Rankine said nothing of the kind, but assumed that the load, carried by the clay under foundations, was proportionate to the depth and left out consideration of side friction. Rankine said his calculation applied only to granular materials and excluded clay. Mr. Crosthwaite's experiments proved conclusively that for granular materials Rankine's theory was correct up to the pressures covered by his work, but broke down with clay. Mr. Crosthwaite was glad to see Dr. Chatley's reference to Prof. Osborne Reynolds' investigations on the dilatancy of granular materials, to which he had drawn attention in his paper above referred to. Reynolds had shown that granular materials subjected to local pressures have the most extraordinary and unexpected properties. For instance, a mass of sand saturated with water, when subjected to local pressure, increased its volume. Now, it has often been assumed that sand and clay under a pile was consolidated and the water between the particles driven out. But if Reynolds' conclusions were true the very reverse was the case, for if the volume of the material under the pile were increased it could only be by increasing the size of the interstices. This increased volume was filled by water taken in from the surrounding material, and the percentage of water under the pile should be increased. That this was the case for a mixture of sand and water could easily be proved by a simple and direct experiment.

It was difficult to carry out a similar experiment with clay owing to the time taken for water to travel between the particles but if it behaved in the same way it would account for the penetration increasing rapidly with the load as shown by Mr. Crosthwaite in his 1916 experiments, for the carrying capacity of clay decreased as the percentage of water increased.

It had for long seemed to him, and, indeed, it had been suggested by others, that any comprehensive theory to cover sand and clay pressure would have to be based on Osborne Reynolds' principle of dilatancy, but the subject was a most difficult one, and would appear to require a superman, like Reynolds, to work it out.

Mr. A. P. I. Cotterell, M.Inst.C.E., said he was glad of the opportunity of echoing the President's congratulations to Mr. Ackermann for his ingenious contrivance for automatically measuring the set of piles. Clearly he has not reached perfection yet, but it already gave valuable results, and, as the last speaker had said, it might be a means of our learning much more about the bearing power of different kinds of soil than we knew at present.

Speaking as an engineer, he was grateful to Dr. Chatley and Mr. Ackermann for the way in which they were tackling the physical properties of clay and revealing more about this almost universal material, but when it came to founding structures he would keep as far away as he could from some of the clays on which Mr. Ackermann had experimented where the water contents were considerable. There were occasions when clays could not be avoided, and then it was we wanted the information these experiments were giving us.

He was struck with the analogy between clay and lead when the pressure of fluidity was reached. Lead, under pressure, entered into its fluid state. So also clay, which was the original material out of which our hardest rocks were built. It was, as it were, those rocks in semi-fluid condition. We may remember that the hardest rocks of Cornwall were once clay until altered by the intrusion of the granite under great pressure and heat.

He would like to call attention to the scientific definitions of clay quoted by Dr. Chatley, and to suggest that it should be regarded not so much as broken down material, as material in the course of being built up, and certain, in course of time, to have considerable bearing power—to look upon it as a material with a future rather than a material with a past.

In conclusion, he congratulated Mr. Ackermann and Dr. Chatley on their work and hoped they would still go forward with it.

Mr. A. Hiley, M.I.N.A., A.M.I.C.E., thanked Mr. Ackermann for his invitation to take a part in the proceedings, which was accepted with all the more pleasure when he reflected on the valuable researches which the authors of the papers had previously contributed to the Society. With regard to the compressive resistance of clay when sufficiently saturated with water to cause it to show definite limits to the pressure of fluidity which Mr. Ackermann had so carefully measured and plotted the results in his diagrams, one thing struck him as noteworthy, and that was the close resemblance between the mechanical properties of that material and that of tallow used for launching purposes. The latter material also revealed well-defined pressures of fluidity, thus, at a pressure of 5·5 tons per sq. ft. at 55° F., and again at 4·5 tons per sq. ft. at 65° F., it will continue to spread out under the loaded surface.

The hardness of the tallow can be determined by means of a strain meter, the amount a $\frac{1}{2}$ in. dia. steel ball will sink into the material under a given load ; but if the experiment be carried further it will be found that if a disc of 3 in. dia. be loaded to the limit of pressure of fluidity it will show approximately a 12 per cent. greater pressure per sq. in. than a steel disc of 12 in. dia., and this would appear to indicate that owing to the periphery of the smaller disc bearing a larger ratio to the area under compression, it was able to exercise a relatively larger frictional constraint against the material tending to flow outwards below the surface imparting the pressure. On this ground he would suggest that where a frictional resistance can contribute its quota in opposing motion of fluidity, it may also be expected to follow that for a given pressure per sq. in. the resistance to motion will tend to appear greater for small areas than for those much larger. In many cases the range of areas needed to be a very wide one before the variation became noticeable, but he could state from experience the following results which illustrated this feature under other conditions. In launching a vessel of 10,000 tons weight carried on an area of sliding surfaces of 6 ft breadth subjected to a pressure of 1½ tons per sq. ft., the co-efficient of friction which opposes the starting of the vessel into motion will be ·042 at 55° F., whereas for a vessel of 100 tons carried on ways of 1 ft. breadth and subjected to the same pressure, this co-efficient of friction would have apparently increased to ·058, and such a boat could not be started if it were only given the same inclination of the ways as would suffice for the larger case. He had said this with the idea that in the experiments bearing on the determining of pressure of fluidity it might not be difficult to extend their scope a little further to ascertain the increase in bearing power which could be obtainable by preventing or partially preventing the lateral expansion or flow of the material under stress, and to add the effects of this suggested influence to the useful information concerning resistances against various head pressures already disclosed. In in any case it would appear desirable always to state the dimensions which go along with experimental results, and preferably to keep to standardised sizes for purposes of comparison so that consistency could be preserved in this way, which was doubtless well understood.

He had followed with interest the clear descriptions of the fineness, composition of clays and their water contents as given in Dr. Chatley's paper. That each of the papers was usefully informative was manifest, though their chief value in practice might run in the direction of giving instructive warning against conditions which had better be avoided whenever loads or forces had to be dealt with which demand robust material for their support. Where conditions met with were unavoidably unwholesome, they had been provided with data for guidance in restricting the loadings to a safe amount for soft, waterlogged ground. Although the mass of information already gained from the researches into the physical properties of clay might cause additional caution in dealings with it, nevertheless, the possibility remained that they might be able to mitigate the evil effects of over-saturation in some instances. One such instance might be cited in the case of concrete piling on a new system devised to accomplish the expenditure of energy in a way which enables the intensity of pressure under which concrete was rammed into the surrounding strata to be controlled at will, so that the frictional grip might be made to reach much higher values than ordinary passive methods could obtain.

Turning to the interesting questions raised in Mr. Ackermann's paper on piling, the apparatus he had made for the purpose of recording the set and recoil, and which he had placed before the meeting for inspection, conveyed a strong impression of the unflagging energy and painstaking care with which he had sought to advance the accuracy of such measurements, especially for cases where a pile was driven from a floating barge. The process of evolving a suitable instrument recalled similar experiments of his own when he required to ascertain the exact deflection of circular girder supports of gun mountings and the deflection of flat plating exposed to blast pressures. For these purposes he devised (1) an inertia gauge in which the marker was maintained stationary by reason of its being supported on a ballasted floating cylinder, whose mass was uninfluenced by a difference in water level in a container, added to this an electric release could time the movement ; (2) marking battens of wood with points to scratch the movement on blackened tin ; (3) a light linen tape with one end fixed to the pile and the other passed through a slight frictional grip on a point carried on a flexible support as to remain sensibly stationary. Of the three the second was better than the first so far as recording the movement was concerned, being much simpler to fit up. The third, easily the cheapest and best to deal with, was the most accurate of all on account of its lightness, strength, and freedom from effects of violent vibrations or such like inertia troubles. On making some more recent observations of a similar nature—this time also concerned with piling—he again made use of the third method, and, as the case was above ground and not afloat, no difficulty stood in the way of satisfactory results being easily obtained. He might therefore be pardoned for asking Mr. Ackermann did he not feel the price he had had to pay in both time and money for the information obtained was somewhat high, and that further simplification was desirable ?

A correct estimate of the hammer blow was needed before the most accurate measurement of a pile-set could yield any reliable result, and he commended to notice the treatment given to this question which had just appeared in "Engineering." He need not trouble to repeat what could there be referred to, but in taking a critical glance at the example given in the paper dealing with a timber pile driven at Teddington, he would make use of some of the formalæ given in his article in "Engineering." Although the knowledge of the principles of piling might become considerably extended, this would probably not alter any established practice where it was efficiently carried out, but rather would it serve to save us from those occasional shortcomings which might otherwise creep in. With regard to the information Mr. Ackermann gave concerning the above-mentioned pile, he might be allowed to correct one or two points of inaccuracy in the figures quoted, feeling sure this would not be taken amiss. The resistance overcome was stated to reach in round figures 100 tons, and the set $\frac{3}{4}$ in. + $\frac{1}{4}$ in. elastic recoil. Consequently, if these figures were taken as given they arrived at the mechanical work done of 100 × ($\frac{3}{4}$ in. + $\frac{1}{8}$ in.), or 87 inch-tons. Now. the energy available was only = 1 ton × 50 in. fall or 50 inch-tons, so that it was inconceivable that more energy than this could be expended, and they must consequently look for the reason of this impossibility. It was this : If the loss due to impact of the 1 ton hammer on the 1·1 ton pitch pine pile be taken into account, it would be found to be 50 per cent. of the initial energy of the hammer, thus affording only 25 inch-tons instead of the 51 inch-tons or 9,526 foot pounds assumed in the paper. The correct value for R, the mean resistance overcome, could not exceed—

$$\frac{25 \text{ inch-tons}}{\frac{3}{4}\text{ in.} + \frac{1}{8}\text{ in.}} = 29 \text{ tons}$$

instead of the amount supposed of over 100 tons which was used in the calculation for E.

Again, taking the value of E as 1,225,000 lb. per sq. in., the force of 29 tons could compress the pile only ·055 in., and not $\frac{1}{4}$ in. in 20 ft. length, which was accepted as the recorded elastic compression. A little further consideration from the practical point of view would indicate that such a pile, driven as described, would not be expected to take a load exceeding 10 tons, and this was shown to be only what was appropriate if the case were calculated correctly.

Mr. H. C. H. Shenton, Past President, said Mr. Ackermann's paper was of special interest to him because he had not only followed his work closely, but was present when some of the experiments with the pile-set gauge were made, and he checked the readings of Experiments 269 (a) and (b), and, as will be seen by reference to the table, the record of the gauge was absolutely accurate.

Mr. Ackermann's experiment made in order to find the load necessary to crush a model cliff of clay was interesting, but no inferences had been drawn. What may be inferred from the behaviour of the clay under pressure was important. Mr.

Ackermann had shown that lead also has a pressure of fluidity. The same fact was proved by experiments made in connection with a line of pipes laid in New York Harbour in connection with the Catskill aqueduct. The joints had to be filled with lead, and they had, moreover, to be flexible. It was found that ordinary caulking would not give the conditions required. The joints were therefore lined with lead and then pellets of lead were forced into the joint through a number of holes tapped radially in the socket of the pipe. Set screws were inserted and the lead was forced into the socket. This was made possible by the fact, found by experiment, that lead will flow readily under the pressure of 700 lb. per sq. in. (= 4·87 tons per sq. in.) steadily applied.

Mr. Ackermann had made experiments in order to ascertain the shrinkage of clay, and he wished to suggest to him that he should now make experiments on the expansion of clay. Prof. Giesecke, of the University of Texas, made an experiment recently by filling a " 3 gang " 2 in. cube brass mould with compacted pulverised clay. This clay was allowed to absorb water while the mould rested on a brass plate. The clay expanded vertically a little more than ¼ in above the mould, and the mould was lifted ·049 in. off the brass plate. It will be seen that Prof. Giesecke found the expansion of clay under these conditions to be 14·95 per cent., but the experiment as reported does not appear to be definite. Prof. Giesecke's experiment was made owing to the fact that change in the moisture content of a 6 ft. layer of clay under a certain building produced a vertical expansion of about 4 ins., and thereby broke the concrete floor slab, lifted iron and wooden columns with their superimposed load off the concrete pillars, and lifted a brick wall, together with a portion of the concrete foundation wall. The vertical expansion in this case appeared to have been 5·55 per cent.

The contraction of clay in dry weather, and possibly the expansion of clay in wet weather, are matters which gave us much trouble in London. Seeing that dryness causes contraction and subsequent settlement, it seemed to follow that such settlement could be prevented if the clay were kept in a moist condition permanently, but the matter did not appear to have received any serious attention. The behaviour of clay as its moisture content increases was most important. An embankment which would stand at a slope at 1½ to 1 under normal conditions would slide as it absorbed moisture, and if the moisture exceeded a certain limit it would become liquid, and would then stand at practically no angle at all. Between these extremes there was much to learn. When excavating, he had traced cracks in the London clay, apparently due to contraction in dry weather, to a depth of 15 ft. Cracks of this kind must become full of water in wet weather, and the effect was probably considerable. He was sceptical as to the efficiency of weeping pipes in retaining walls. He had known clay banks which were quite free to drain without any wall in front of them which absorbed enough water to make them suddenly flow out flat.

With regard to the rebound of piles, certain tests made in America by Mr. J. F. Greathead for the Public Service Commission showed clearly that clayey sand and also gravel had distinct elastic properties. Experimental piles driven showed a distinct recovery after the load had been removed. For instance, piles sunk in sand containing 10 per cent. of clay settled $7\frac{1}{2}$ ins. when a load of 40 tons was applied, and then came to rest. The load was supported for three minutes, and was then removed, after which the pile extruded nearly $\frac{1}{2}$ in. A second pile settled 8 ins. when loaded with 40 tons, sustained this load for three minutes, and rose $\frac{1}{2}$ in. when the load was removed. The load was then re-applied, the pile sank 1 in., rebounding slightly when the load was removed. The fact that the pile which had maintained a load of 40 tons for three minutes sank 1 in. when the same load was re-applied was instructive, but another experiment was more instructive. In this case a pile loaded with 80 tons settled 11 ins., rose $\frac{1}{2}$ in., settled over 1 in. when the same load was re-applied, rose $\frac{1}{4}$ in., settled a further 1 in. on re-application of the same load, rose $\frac{1}{4}$ in., settled a further $\frac{1}{2}$ in., and rose $\frac{1}{8}$ in., all with the same load of 80 tons. The bottom end of this pile was on gravel. Another settled and rose five times on the application and re-application of 20 tons, settling 5 ins. on the first application, and showing a final total settlement of $7\frac{1}{4}$ ins., the average recovery being a little under $\frac{1}{2}$ in. Other trials gave similar results in clayey sand and in gravel. All this went to show (1) that the earth was elastic, and (2) that after settlement and recovery the pile would generally sink further under the same load. At Pennsylvania State College the distribution of pressure under piles was recently measured at various distances and depths, the load being applied by an hydraulic jack, the resisting pressure of the earth being measured. Tests on different soils with different pressures gave similar results. It was found that loaded piles produced what is described as a bulb of pressure. Thus, at a depth of 6 ins. below the surface the pressure was about 90 per cent. of the maximum soil pressure, while at a depth of 59 ft. it was only 3 per cent. If a hyacinth bulb were cut into halves vertically the various layers would represent graphically these earth pressures, the largest outside layer representing the least intensity. It was thought that this fact explained how a soil can take great pressures, the bulb merely spreading the load over such a great area that the stress was reduced to a value that the soil could sustain without settlement. This naturally affected the spacing of piles, there being no advantage in having them too close together. The bulb may also explain rebound and resettlement. When the load was released, an elastic expansion of the bulb took place, but in doing so the bulb partly broke down, that was, the earth was disturbed, and the bulb was formed again at a lower level on re-application of the load.

One read of work in which the load on the piers driven to support a building was maintained on each pile by means of hydraulic jacks. The rebound being held down until the final permanent load was applied, the idea being to prevent the subsequent settlement which might otherwise be expected to take place.

Dr. C. V. Drysdale, O.B.E., D.Sc., F.Inst.P., M.I.E.E., congratulated Dr. Chatley and Mr. Ackermann on their valuable papers, and said that as a physicist he was interested in the subject from another standpoint. For example, in the problems of submarine acoustics and sound ranging in which explosion or acoustic impulses were transmitted under water, it would appear at first sight that the only phenomena concerned were the direct transmission through the water and its acoustic properties ; but the question was by no means so simple. There were four paths from the transmitter to the receiver : (a) direct, (b) by reflection at the surface, (c) by reflection at the bottom, and (d) by transmission through the bottom. Theory indicated that when the distance between the transmitter and receiver was large in comparison with their depth, (a) and (b) were practically equal in intensity and opposite in phase so that they cancelled out. It therefore appeared that (c) and (d) were the chief factors, and these depended on the physical properties of the bottom, so that a complete knowledge of these properties was very desirable.

A similar problem arose in connection with the pilot or leader cable now coming into use for guiding ships along harbours or channels in fogs. The electro-magnetic field from such a cable was strongly absorbed and distorted by the conductivity of the water at sonic frequencies, and the electrical conductivity of the bottom had also an influence. He was therefore glad to see that a start had been made in determining the physical properties of clay, and hoped it would broaden to include the phenomena above mentioned.

Allusion had been made to the increase of volume of a granular material by shearing stress due to the re-arrangement of the particles as pointed out by Prof. Osborn Reynolds. This was a phenomenon which could always be seen on a sandy beach from which the tide had just receded, leaving the sand glistening. At every footfall a dry patch is seen around the foot, and when it is lifted a small pool of water was found. The same effect was seen when a walking stick was thrust into the sand, representing a miniature pile.

He was interested in Mr. Ackermann's simple and effective devices for measuring the movements of a pile. This formed an application of a principle which had so far been employed only in seismography and to a limited extent in acoustics, but which appeared destined to have many other useful applications. Instead of referring the displacement of a body with respect to an object fixed to the earth, advantage was taken of the inertia of a large mass to maintain it at rest in the absence of a force. It was essential for the accurate utilisation of this effect that the force of gravitation on the mass should be balanced over the whole of the range to such an extent that the natural periodic time of its oscillation was large in comparison with the time interval of the displacement ; so that if this were effected by a spring, that spring should be as long as possible. The excellent results obtained by Mr. Ackermann's simple apparatus demonstrated the effectiveness of the principle.

Mr. Percy J. Neate, M.I.Mech.E., said that what he thought engineers wanted as a preliminary for pile-driving was a test borehole from which a series of cores could be obtained intact and tested for viscosity and water content.

Pending the invention of a suitable tool, information gained from the sets of the first pile driven on a job, if carefully analysed by any or all of the appropriate formulæ set forth in the two papers would yield data of extreme value.

He then pointed out that in two pile-driving diagrams taken by him (one of which was published by Mr. Ernest Latham in the Proc. Inst.C.E. last year), four or five rhythmic vertical oscillations of the pile after a blow were disclosed. It seemed clear that any form of ratchet device for measuring set or recoil, if of sufficient delicacy, would measure the sums of all the upward and downward vibrations respectively, and so unduly magnify the record, quite apart from any further magnification due to the waves of compression found to be set up in the suspension spring.

The speaker further pointed out that his diagram was produced by a pencil moving truly horizontally (along a straight-edge attached to a fixed support) on a sheet of paper fixed to the pile, and he considered that this construction eliminated undesirable friction and inertia stresses.

He added that he believed the suspended weight to which Mr. Ackermann's recording pencil was attached could be reduced to a mere fraction of its present value with considerable advantage.

Mr. M. Holroyd Smith, M.I.E.E., said he had attended many meetings of the Society and listened to many interesting papers, but the discussion that evening was the best he had heard. All the speakers were evidently well acquainted with the subject matter.

He noticed there was a difference of opinion among some of the speakers on the question whether there was any friction on the sides of piles when they were being driven. He had driven very few piles, but he had driven hundreds of nails, and at each stroke of the hammer the nail penetrated until it had been driven up to the head, but when he endeavoured to withdraw that nail it had taken a great deal of pulling out, therefore, in his opinion, there must have been a considerable amount of side friction during the driving, and with his unmathematical mind he could not see why the same thing did not apply to the driving of piles.

He was not a member of the Society, but the Presidents and the Secretary had so often invited him to attend the meetings that he felt he must express to them his thanks for their courtesy and kindness. He took that opportunity of doing so because in all probability it would be his last visit as he was leaving London. Through the whole of his association with the Society he had always received a kind reception. His thanks were especially due to their good Secretary, Mr. Ackermann.

Mr. E. G. Walker, B.Sc. (Eng.), A.C.G.I., A.M.I.C.E., wrote stating:

Dr. Chatley enters into details of the objections which have been raised to the definition of clay given by the Special Committee of the American Society of Civil Engineers on Materials for Road Construction. The placing of the Road Materials Committee's definition in juxtaposition to those of the various physicists and geologists without any discrimination is hardly fair, in that the view-point of the Committee differs fundamentally from that of the various scientists referred to in the paper. The Committee was appointed to report on materials for road construction and on standards for their test and use. They drew up, therefore, a definition which would enable a differentiation to be made on the job between the various materials which occur, thus clearing the way for proper specification of various roadmaking processes. Their definitions, taken from the final report of the Committee, 1918, cover a range of materials from one-tenth of an inch downwards, as follows :—

1. Gravel : Small stones or pebbles usually found in natural deposits, more or less mixed with sand, clay, etc., but in which mixture the particles which will not pass a 10 mesh sieve predominate.

2. Sand : Finely divided rock detritus, the particles of which will pass a 10 mesh to be retained on a 200 mesh screen.
3. Clay : Finely divided earth, generally silicious and aluminous, which will pass a 200 mesh sieve.
4. Silt : Naturally deposited fine earthy material which will pass a 200 mesh sieve.
5. Loam : Finely divided earthy material containing a considerable proportion of organic matter.

(*Trans. Am. Soc. C.E., Vol. LXXXII., pp.1,422-7.*)

This series of definitions obviously partakes of the nature of a working classification for specification purposes, and cannot be compared with the definitions based on geological and colloidal chemical considerations, unless the difference of origin is kept in view.

The value given for the tensile strength of wet mud, namely, 15 lb. per sq. in., seems remarkably high. It would be of service if the author would state exactly what his figure represents.

In connection with the detailed investigation into the nature of soil materials which is being undertaken by the Special Committee of the American Society of Civil Engineers to codify the present practice on the bearing value of soils for foundations, etc., careful experiments have been made at the Engineering Experimental Station of the Iowa State College on the mechanical properties of clay in its undisturbed state as found in the natural bed. In this way all errors and variations introduced by the preparation of specimens from sample material removed from its original environment are eliminated. Experiments have been made on tensile, compressive and shear strengths on two beds of blue and yellow clay respectively. The average results of the tensile tests are :—

		Tensile Strength in lb. sq. ft.		
Material.	*No. of Tests.*	*Max.*	*Min.*	*Average.*
Blue Clay	14	322	92	255·0
Yellow Clay	10	299	95	211·5

These values are only one-tenth of those given by Dr. Chatley for wet mud, although they agree with the range of values given by Airy in 1881 (*Min. Proc. Inst.C.E., Vol. LXV., p. 188*), namely, from 160 to 800 lb. per sq. ft. In connection with the Iowa experiments it is interesting to note that on the three occasions in which tests were made after rain the results were 95 lb. per sq. ft. (yellow clay) and 314 and 240 lb. per sq. ft. (blue clay). One cannot generalise on isolated experiments, but it would seem that surface wetting did not have much effect on the tensile strength of blue clay, although that may not have been the case of the one experiment on the yellow. In any case, all results fall short of the author's figure of 15 lb. per sq. in. (2,160 lb. per sq. ft.).

The Iowa experiments on shear strength give results more in accordance with the author's figues. The averages are :—

		Shearing Strength in lb. per sq. ft.		
Material.	*No. of Tests.*	*Max.*	*Min.*	*Average.*
Sandy Loam	3	353	290	312
Yellow Clay	8	695	440	584
Blue Clay ...	9	517	365	426

The clay mud which the author deals with in the paper may reasonably be expected to have a lower shear value, and he places these at 200 to 300 lb. per sq. ft. A full account of the Iowa experiments is given in the Sixth Progress Report of the Special Committee on Soils which was issued in January of this year (*Proc. Am. Soc. C.E., Vol. XLVIII., pp. 523-580*).

The radial compression or flow round a pile, which the author refers to in the last paragraph at p. 143, has been studied by Zimmerman in Germany. An account of his experiments is given in *Beton und Eisen*, Aug. and Sept., 1915. He concludes that there is a practical limit to the zone of compression which exists around the pile. The compressive effect does not extend beyond a distance from the centre of the pile equal to about 1¼ times its diameter. The maximum compression seems to exist at a radius varying from ¾ to 1 diameter, the exact position depending apparently on the form of the point of the pile. The fact that the radial distribution of compression varies with the point form would seem to corroborate to some extent the theory of Ackerman which Dr. Chatley mentions.

Granted the author's premises, in Appendix No. 3, then there is no doubt that his conclusions are correct. But he makes two assumptions, one that there is a " mean friction per unit of surface," and the other that this " friction " varies according to the law :—

$$f_n = f_o - ch.$$

Both of these may be inapplicable to cases which occur in practice when piling in mud. He places no limitations on the applicability of his formula, but surely before a formula is developed and applied it is essential that the bases from which it is deduced should be fully proved. The deduction of the formula itself is an exercise of relatively immaterial importance. In this case there is no mention of the evidence upon which the fundamental assumption is made. The hypotheses and/or conditions upon which the rules of Rankine, Ackermann, and Crosthwaite are based differ almost wildly among themselves and from the author's. Surely the first thing to do is to endeavour to arrive at what is the proper assumption to make in regard to variation of frictional supporting force with depth—if one there be, that can reasonably represent practical conditions—rather than to lay down a formula which, if the basic assumptions are proved to be correct, is simply arrived at but which otherwise is misleading.

Whilst on this point it may be well to mention a limitation which is usually ignored in the development of the formulæ of this sort, as well as by engineers in practice. It is not a logical conclusion that because a test pile in any particular case will support a given load that *n* similar piles similarly driven in the same material will support *n* times that load. This statement is apart from considerations of variations in the nature of the soil, and holds even on the assumption of uniform physical properties of the material. The experiments of Zimmermann and those of Ackermann mentioned by the author show that the support of a pile is due to the mass of earth surrounding the pile. The influence of the pile on the soil extends to some distance horizontally and becomes negligible at a radius from the pile centre which most likely differs in different cases. Zimmermann concludes that the limiting radius is about 1¼ times the diameter of the pile ; failure of piling in bad ground indicates that this may be exceeded sometimes. It is of primary importance, therefore, to allow for the pitching of the piles when designing a foundation to carry any particular load. If close pitching is resorted to, the basis of calculation must be entirely altered. With the overlapping of the cylinders of earth supporting each pile it is evident that a considerable reduction of supporting power results, so that, at the limit, the frictional supporting surface reduces to the perimeter of the piled area multiplied by the depth of the piling, resulting in a corresponding reduction in the magnitude of the frictional supporting forces. If the area is of any extent, this means practically the only effect to the piling is to act as a pier of consolidated earth and to transmit the load from the ground surface to another surface at a lower level. In some cases this may be sufficient, but in many, probably the majority, of cases, the lower stratum is not appreciably better able to support the load than the upper one. Hence it becomes a matter of importance to spread the piling sufficiently to make certain that each pile can carry the load which a test shows to be practicable. The writer has in mind the case of a large grain store which was built in 1919 on a poor foundation. The installation is a fairly large one, containing 63 circular storage bins 178 ft. high, and is built on a concrete slab 3 ft. thick, extending over the whole area and supported on timber piles spaced 2 ft. 6 ins. apart. Before the construction was completed the foundation had slipped to an alarming extent, although, on the basis of the results obtained with isolated test piles, there was ample piling to support the whole weight of the building and its full working load in addition. Investigation showed that the failure was due solely to the closeness with which the piles had been pitched in a soil which consisted mainly of a filling of dredging spoil recently deposited, and therefore of poor supporting value. The remedy was found in this case by driving closely pitched piling over a fairly wide area around the outside of the building, thus, by lateral compression of the surrounding soil, providing the necessary support to the interior earth. This proved successful. Virtually, by giving lateral support, the bearing value of the inner soil was increased sufficiently to balance the reduced supporting power of the interior piling.

Finally, the writer would like to emphasise Dr. Chatley's conclusion given at the end of the paper. It is a matter which cannot be too strongly impressed on engineers concerned with foundation work that soils must be treated in the same way as the various other materials of construction. Engineers have, after many years of experience and discussion, got to realise the importance of bearing in mind elastic limits and fatigue limits of their materials when selecting working stresses. Yet many do not fully realise that in soils they have materials, though differing from other structural materials sufficiently to require special study on their own account, are, within limits, elastic. In designing any structure in which stresses are applied to soil it is as necessary to see that the loads are supported only by the elastic reaction of the material, as it is in the case of mild steel. Limiting working stresses must be chosen with the same regard to the limits of the elastic properties as in any other case.

Mr. James Mitchell, M.Inst.C.E., wrote that it was unfortunate that the same word—flow—was used to indicate certain kinds of movement in the case of both fluids and plastic solids. This was likely to cause confusion with regard to the so-called " pressure of fluidity " as applied to such materials as clay and lead. Thus, in Dr. Chatley's paper it is stated, at p. 137, that " mud flows under " sufficient pressure (the pressure of fluidity) as a viscous fluid," while at p. 143 reference is made to " fluids of high viscosity, such as clay." Again, we find, at p. 139, " about the only feature " characteristic of all clays is that of plasticity when wet " ; at p. 142, " Plastic flow which is produced at a constant rate, proportional to the distorting stress, and is permanent. This " steady flow is the characteristic of a fluid" ; and at p. 143 " under " sufficiently great stress all materials will flow." From these statements it would appear reasonable to infer than an extruded bar of gunmetal would be more properly described as a fluid body than as a solid ! While there was no such thing as a sharp dividing line between fluids and plastic solids, any more than there was between animals and vegetables, it was well to keep in view the broad general distinction that in a fluid the smallest stress, if only continued long enough, would cause a perceptible and increasing change of form, while in a solid substance continuous alteration of form was produced only by a stress exceeding a certain value. While, therefore, this steady flow was one of the chaarcteristics of a fluid, it was not (as stated by Dr. Chatley) " the " characteristic.

Mr. Ackermann's experiments described in Paper I., p. 102, shewed—as might have been expected from everyday observation —that clay could not be converted into a fluid by pressure, and it was difficult to imagine why the result should be in any way different when the pressure was produced through the medium of a pile, and in a position where direct measurement had so far proved to be impracticable.

The danger of using the expression " pressure of fluidity " with regard to clay, lead, and other plastic solids was that it tended to convey the implication that, when subjected to certain pressures, the materials acquired, in some may, the most characteristic property of fluid bodies, viz., that at any point in the body the pressure is the same in every direction.

With regard to the pile-set gauge described by Mr. Ackermann, the problem he had set himself was a difficult one, and he had dealt with it in a very ingenious manner. It would appear, however, that what the gauge recorded was not the set of the pile, but the set of the pile minus the distance travelled by the spring-suspended weight under the influence of gravity, the resultant being complicated by the surging due to the inertia of the weight and the elasticity of the spring. Obviously, the readings would be greatly affected by the time taken by the pile to move under the blow of the hammer. If the rate of movement happened to coincide with that of a freely falling body, the pencil would draw a horizontal line, complicated by the before-mentioned surging effects. The effect of lowering the support of the spring more rapidly would be to compress a portion of the upper end of the spring, thus allowing the suspended weight and the remaining portion of the spring to fall freely under the pull of gravity, while a wave of compression would travel forward and backward along the spring till finally damped out. The weight, therefore, could not be regarded as " practically fixed in space for " a fraction (say a tenth) of a second." With regard to the application of the gauge to the driving of a full-sized pile, the statement (p. 19) that the total error of the gauge was plus 2·6 per cent. was hardly an adequate description of the results shewn in Table II., where the percentage of error ranged from – 9 to + 25.

Mr. A. O. Edwards, M.S.E., wrote stating it is difficult to see what relationship the pressure of fluidity of a metal, *e.g.*, lead, can have to that of a wet clay. It is known that most metals exhibit the phenomenon of flow under mechanical pressure, due to intercrystalline slip which does not appear to bear any connection with the plastic deformation of a colloid bearing material. While complimenting Mr. Ackermann on the ingenuity of apparatus, the results obtained on an artificially moulded clay, *e.g.*, model cliff wall, probably do not represent in actual figures those which would be obtained on the same clay *in situ* owing to the difference between the natural and artificial grain packing.

It would be interesting to know whether Dr. Chatley considers that the plasticity of clay is due chiefly to the presence of colloids or whether he regards it as a mechanical factor due to the particles being lubricated by a suitable fluid having a high attraction for the particular solid particles. With a clay of definite plasticity there exists a maximum of pressure and a minimum of consistency between which the clay can be given a definite form (Bourry). Any attempt to obtain definite values for these limits are an aid to civil engineering problems.

Mr. Ernest Latham, A.C.G.I., M.I.C.E., wrote stating that he had read Mr. Ackermann's fourth paper with interest, especially that section dealing with the question of pile-set gauges. He had thought that he had been the first to attempt the creation of such a recording instrument, but as the result of an article communicated to *Engineering*, he had subsequently found that one of the first attempts had been made many years ago by Mr. James N. Stirling, M.I.C.E., now Borough Engineer of Helensburgh. In the experiments which Mr. Latham had carried out he had relied on the inertia of a liquid and the trapping of a definite quantity of such liquid passing a non-return valve. It was obvious that if such a gauge could be developed the amount of liquid so trapped would be some indication of the penetration of the pile due to each blow of the hammer. He was glad to note that he had stimulated research in this direction, and congratulated Mr. Ackermann on his work. The patient investigation by which errors have been reduced, especially by the combination of the ratchet and spring-borne weights, was certainly ingenious. The author would remember that at one time he considered inertia was not a necessity to his invention, and he was therefore glad to notice at p. 159 that Mr. Ackermann specifically referred to the inertia of the weight. Speaking as a practical civil engineer, it was obvious that the experimental apparatus illustrated would not be practicable for heavy contract work, and the next step, therefore, was clearly to design a small enclosed instrument capable of rapid attachment to a pile, and which could be marketed at a reasonable price.

Mr. James N. Stirling, M.A., B.Sc., Assoc.M.Inst.C.E., M.Inst. M. & Cy.E., wrote saying :—

I am much impressed with the most excellent work which has been done by Dr. Chatley and yourself, and I am confident that the contributions made by you will be of the highest value to engineers engaged on works of piling in clay.

You ask for particulars of a pile-set gauge used by me some years ago.

Between 1906 and 1908, when Resident Engineer for the Clyde Navigation Trust in charge of the construction of the engineering portions of the Renfrew Workshops, I found that there was a tendency to gauge the bearing capacity of a pile by considering only the apparent set produced in the pile by a hammer of known weight falling through a known distance. It was evident that while this simple calculation was unsound, even when the true travel of the pile under the blow was known, it was of still less value when the apparent set as determined by the dumpy level or by a similar method was used in the calculation. Experience with the gauge to be described proved that a 12 ins. square pitch pine pile, when well down in the mud of the Clyde Valley, frequently penetrated $\frac{7}{8}$ in. at a blow and recovered immediately $\frac{3}{4}$ in., so that when measurements were taken by dumpy level the apparent set was $\frac{1}{8}$ in., while the true set was $\frac{7}{8}$ in. The result of this error was to make the bearing capacity appear seven times what was intended by the usual formula. The gauge (Fig. 10) established the amount of this difference. It consisted of two pieces, the first was a base carrying a fixed cylinder in a vertical position and a fixed vertical scale. The second part of the instrument was a moving piece, and it was built up of a piston and piston rod sliding in the cylinder, and, rigidly connected to these by a block of wood, an index moving over the face of the fixed scale. To control the motion of the moving part an adjustable friction grip was secured to the cylinder. It steadied the motion of the piston rod, and was found sufficient to overcome movement due to inertia. The air in the cylinder was free to leave and enter it so that the cylinder was merely a convenient friction guide for the piston rod. The instrument was set on a timber batten supported independently of the pile, and in use it lay close against the face of the pile itself. The motion of the pile was communicated to the index by means of a piece of wood nailed to the pile and projecting from it sufficiently far to engage the top of the piston rod ; or more often the motion of the pile was communicated by means of the projecting edge of the hammer itself (the latter method was the one in regular use when recording the final set of piles, and is assumed to be used in what follows).

When the instrument had been set up with the hammer resting on the pile, the moving portion of the gauge was pressed up against the bottom of the hammer (or the piece of wood nailed to the pile to give motion), and the scale was read ; when the hammer was raised and allowed to fall the piston rod and the index were forced down and left in the lowest position reached by

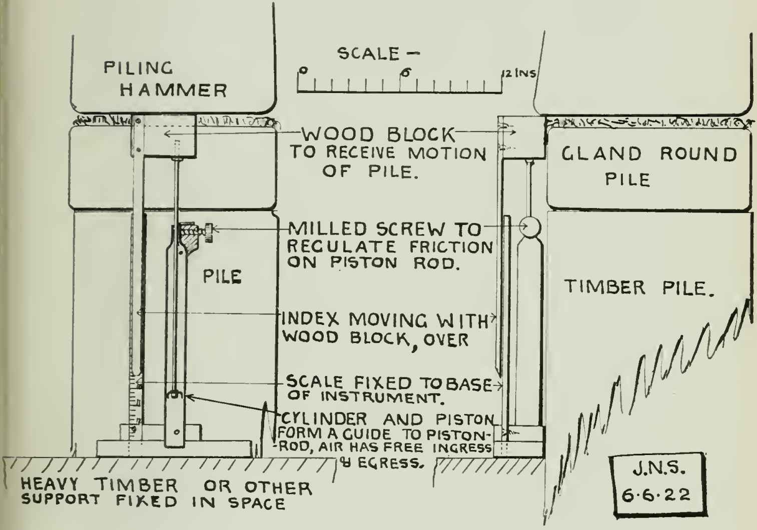

PILING HAMMER
SCALE –
0
6
12 INS
WOOD BLOCK TO RECEIVE MOTION OF PILE.
GLAND ROUND PILE
MILLED SCREW TO REGULATE FRICTION ON PISTON ROD.
PILE
TIMBER PILE.
INDEX MOVING WITH WOOD BLOCK, OVER
SCALE FIXED TO BASE OF INSTRUMENT.
CYLINDER AND PISTON FORM A GUIDE TO PISTON-ROD, AIR HAS FREE INGRESS & EGRESS.
HEAVY TIMBER OR OTHER SUPPORT FIXED IN SPACE
J.N.S. 6·6·22

FIG. 10.

the hammer and pile, the scale reading was again taken ; the difference between this and the first reading gave the total yield of the pile under the blow ; the hammer and pile immediately recovered and left a space between the top of the piston and the bottom of the hammer. The moving part of the gauge was again raised by hand against the hammer, and a third reading taken. The difference between this and the first reading gave the apparent set as usually measured. This apparent set was frequently as small as $\frac{1}{7}$th of the total motion of the pile.

I am glad to be able to confirm the remarkable fact so convincingly brought out by your beautiful diagrams that the apparent set of a pile as ordinarily observed is not a very reliable basis on which to estimate its safe bearing capacity.

Mr. Hal Gutteridge, A.M.I.Mech.E., Mem. Technical Inspection Assoc., wrote that an analogy might be drawn between the author's pile-set gauge and the steam engine indicator in that they are both primarily intended for testing purposes. The gauge would be used on the test piles, which would be put in as frequently as necessary to suit any changes or anticipated changes in the nature of the strata to be pierced, in the same way as an indicator is used only when altered conditions occur in the cylinder or for investigating new types of engines.

He had had the pleasure of attending a test of the autographic pile-set gauge at Butler's Wharf, on June 6th, 1922, where simplex piles were being put in by Messrs. J. & W. Stewart. The autographically recorded results registered by the gauge, for all the six blows recorded, agreed with the readings taken by a level, placed about 20 ft. away from the pile in every case except two, in which there was a difference of $\frac{1}{32}$ in. The curves obtained by means of the gauge exhibited several interesting facts, one of which was that the ratio of the elastic recoil to the set of the pile became greater as the set decreased owing to the increase of resistance of the soil to the pile. This is shown by the following table :—

I. Set in 16th in.	II. Elastic Recoil in 16th in.	Ratio II. to I.	
13	9	0·69	mean 0·55.
13	7	0·54	
14	6	0·43	
6	5	0·83	mean 1·36.
4	7	1·75	
4	6	1·50	

Thus, when the set was about $\frac{3}{4}$ in. the recoil was 45% less than the set, but when the set was about $\frac{1}{4}$ in. the recoil was 28·5% greater than the set. The elastic recoil, in fact, tended to be constant.

Dr. Herbert Chatley's reply to the discussion :—

Apropos of the President's remarks, there were numerous localities where the mud was deep (say more than 200 ft.), and so soft that the load which it can safely bear was small (*e.g.*, 1,700 lb. per sq. ft.). Mr. Crosthwaite's suggestion that the Osborne Reynolds dilatancy might involve liquefaction under the point of a pile was interesting, but it should be pointed out that the increase of void volume did not continue indefinitely with the pressure.

In regard to the formula attributed by the author to Mr. Crosthwaite, the information on this point was gained at second-hand. In any case it represented a conceivable type of friction variation. Similarly in regard to the Rankin formula ; it simply referred to the case where the surface friction varied directly as the pressure.

Dr. Drysdale's remark on the transmission of sound in mud was very pertinent. Something might be done with seismographs to indicate the energy losses in pile driving.

The problem of the stability and distribution of the water content was a most important question which should be investigated.

Adsorption differed from absorption in that the water was considered to be bound to the surface of the grains in a very stable manner, almost chemical. A recent report by the Faraday Society on the physico-chemical properties of the soil contained valuable information on this and other matters.

The conversion of mud into clay and then into shale, slate, etc., raised the questions of cohesion in relation to density, fineness and water content, concerning which there was much more to be known.

With respect to Mr. Walker's valuable remarks, the material "clay" should be the same whatever its use. As to the tensile strength, this depends on the *water content*. With "normal" water content, the strength is small. As to the "wild" variation of the assumptions, they were a deliberate attempt to show the state of our ignorance and its consequences. In reply to Mr. Edwards, as to the cause of plasticity, Dr. Mellor's paper in the Faraday Society's report deals rather fully with the question.

Mr. Ackermann's reply to the discussion :—

Mr. Crosthwaite had referred to his paper on *Earth Pressures*, published in the *Proc. Inst.C.E., Vol. CCIII., 1917*, at p. 187 of which he had stated that " with sound clays and damp sands it was found that friction [on the sides of the pile] did not come in. The material escaping from under the plunger carried with it the superincumbent material, leaving an annular ring round the plunger. This must have ensured that in these experiments at least friction did not affect the result."

It was unfortunate that Mr. Crosthwaite had not recorded in that paper what percentage of water there was in the clay used for each experiment. One was not even able to guess the percentage implied by the adjective " sound," but, fortunately, the weight of the clay per cubic foot had been given, and, combining this with the experimental data given by the present author in his first and second papers, and that given by Mr. Crosthwaite at p. 150 *loc. cit.*, the following table had been compiled :—

No. of Mr. Crosthwaite's Experiment.	Weight of Clay in lb. per c.ft.	% of water in the Clay.	Max. Stress in tons per sq. ft. recorded by Mr. Crosthwaite.	Pressure of Fluidity in tons per sq. ft.
23A	109	29	6·25	0·55
55	112	26	1·47	1·45
56	109	29	0·625	0·55
65	112	26	2·86	1·45
66	119	21	6·88	8·03
67	115	24	6·88	3·83
68	115	24	5·53	3·83
69	115	24	6·88	3·83

The most remarkable thing about these results is the enormous difference between the results of Nos. (23A) and (56), both of which referred to the same clay containing the same percentage of water. In the former the maximum stress was 6·25 tons per sq. ft., and in the latter exactly one-tenth of that amount. There was a similar though less discrepancy in the case of Nos. (55) and (65).

The results which bore on Mr. Crosthwaite's statement about an annulus were in the last two columns. It would be seen that in every case, except No. (66), the pressure of fluidity was exceeded, and in most cases considerably, while the corresponding curves at p. 150 were parabolæ (as stated by Mr. Crosthwaite, thus agreeing with the author's curve for his experiment (90), given at p. 60 of his first paper), *i.e.*, they had no long horizontal portions such as discs gave when the pressure of fluidity had been reached (*vide* p. 57, I.). Now, if the vertical sides of Mr. Crosthwaite's flat-ended cylindrical piles were not in contact with the clay, how was it they did not act exactly as discs, to which they would be equivalent if their sides were free? Mr. Crosthwaite stated that "with stiff clays an annular space was formed." Clay containing 29 per cent and 26 per cent. of water was certainly not stiff. That containing 24 per cent. was fairly so, and when the water content was only 21 per cent. the clay was decidedly stiff. In this one experiment, however, the pressure of fluidity was not reached, but it was sufficiently nearly approached for the curve to have shown a stronger tendency to become horizontal *if the sides of the pile had been free.* The stiffest clay into which the author forced a *pile,* Exp. (122), contained 23·6 per cent. of water. The maximum load on the pile divided by the area of its end gave a stress of 21·8 tons per sq. ft., but the pressure of fluidity of the clay was only about 4½ tons per sq. ft. The difference could only be accounted for by the friction of the clay on the sides of the pile, and no annulus could be detected, though it was true the pile in that case was a much smaller one (1 c.m. diam.) than Mr. Crosthwaite used.

Mr. Crosthwaite did not obtain the characteristic fluidity curve when the disc was allowed to come entirely to rest before the next increment of load was put on. This was an interesting confirmation of the author's record in Paper III. of the "setting" of clay.

The author was particularly pleased to have Mr. Hiley's remarks in view of his admirable articles on "The Efficiency of the Hammer Blow and its Effect with reference to Piling," which were then appearing in *Engineering*. One of Mr. Hiley's methods of measuring the maximum recoil of a pile was commendably simple, but it needed a point fixed in regard to the earth. The author's autographic gauge did not need such a fixed point, being designed more particularly for piles standing in water and driven from a floating barge. The autographic curve, too, gave the whole story and not merely the maximum recoil and final set. It was not in the least suggested that an autographic pile-set gauge should record every blow on every pile, any more than that every stroke of every steam engine should be recorded by a steam engine indicator. The latter was used occasionally for a few strokes of some engines. Such use had proved useful, and the author thought his pile-set gauge might prove useful, to a less degree, in a similar manner.

Mr. Hiley had misunderstood the author in regard to the resistance of the pile to motion. It was carefully stated in the paper that the *maximum* compressive force on the pile was 231,240 lb. (103 tons). Mr. Hiley had treated this quantity as being the *mean* resistance, thus doubling the work done on the pile. His criticism had, however, caused the author to reconsider his calculations, and in doing so he saw that the effect of the 10 ft. length of pile above the pile-set gauge should be taken into account. As the 20 ft. length of pile below the gauge had elastically compressed $\frac{1}{4}$ in., it was reasonable to assume the upper 10 ft. had compressed $\frac{1}{8}$ in., making the total compression $\frac{3}{8}$ in. Proceeding then as before, the value of R, the maximum force, was 92 tons instead of 103 tons, while the mean resistance of the ground (not previously given) was 47 tons. If the elastic recoil and the weight of the pile were both disregarded (*e.g.*, as they were by J. L. Robinson in working the examples at pp. 275 and 311 of his "Elements of Dynamics") then the value obtained for the maximum force was no less than 136 tons instead of 92, and the mean resistance was 69 tons instead of 47, thus showing the great importance of allowing for the elastic recoil and hence of measuring it by means of the autographic pile-set gauge.

Mr. Shenton called attention to the fact that the author had not drawn any inference from the experiment (280) with the model cliff. The author should have pointed out how very weak the clay in that form was compared with clay surrounded by more clay of the same kind, as in the case of the pressure of fluidity experiments. The cliff clay contained 25·5 per cent. of water, and its pressure of fluidity was thus probably 2,000 grams per sq. c.m. [obtained from the curve Set XX., facing p. 212 of Paper II.], but the maximum compressive stress on the cliff clay was only 207·5 grs. per sq. c.m., *i.e.*, only one-tenth in the amount ! This was certainly an important result, showing the dangerous effect of removing even the supporting effect of the surrounding clay. This would account for many landslides where a cutting had been made. It should be noted, too, that in spite of the clay being in a very plastic state, it failed by shearing.

Mr. Neate referred to his own semi-autographic pile-set diagram. The difficulty with that was to slash the pencil by hand along the fixed straightedge at the right moment. The important portion of such a curve was drawn in about $\frac{1}{100}$ of a second, and this might easily be missed unless the apparatus were entirely autographic. Furthermore, one could not be sure the hand-moved pencil had a purely horizontal motion. In the hurry it might be given some vertical motion, which would spoil the record.

Mr. Neate suggested a reduction of the mass of the suspended weight. The guide-rods of the author's gauge introduced some friction. At first this was thought a disadvantage, but experience has shown that it was just sufficient to prevent the oscillation of the suspended weight, which remained remarkably steady even when the pile was subject to a rapid succession of heavy blows. If the weight were too light the friction of the guide-rods might be sufficient partly to drag the weight down with them, and there did not seem to be any advantage to be gained by a reduction of the weight, which was only 1 kilogram.

Mr. Mitchell (and others in conversation) objected to clay being considered as acting like a fluid under certain conditions. Their objections should be conveyed to the clay in the hope that it might mend its ways ! Mr. A. L. Bell, in his paper on the *Supporting Power of Clay* (*Proc. I.C.E., Vol. CXCIX, 1915, p. 237*) quoted the late Sir George H. Darwin, F.R.S., as saying : " There is certainly no kind of earth with such perfect viscosity as that of pitch, yet some clays approximate to it," and at p. 240 *loc. cit.* Mr. Bell's experiments *proved* that the pressures of clay on planes at right angles were the same within 1 per cent. to 6 per cent. Some of the author's experiments strongly indicated the same result. Surely it was merely a matter of relativity again. What was commonly called a fluid was a substance which, when not confined, flowed laterally due to the earth-pull on it. When the vertical force was sufficiently increased, clay also flowed laterally, and the author's cliff experiment (280) showed that the necessary vertical force, when the clay was not confined laterally, was far less than the pressure of fluid.

Mr. Mitchell thought the suspended weight surged, but it did not, owing apparently to the damping effect of the friction of its guides. Even if it were not guided, its natural period of vibration (as recorded in the paper) was so slow that the effect on the curve drawn in $\frac{1}{10}$ sec. would be practically nil. The results obtained with the gauge proved that the resultant effect of all the possible evils was practically negligible. Since Paper IV. was written Messrs. J. & W. Stewart, the piling contractors, kindly arranged for the author to test his gauge on a Simplex steel pile-tube 16 ins. diam. and 30 ft. long, driven by a 38½ cwt. hammer dropped in all cases about 5 ft. The test took place at Butler's Wharf, Shad Thames, S.E., on June 6, 1922. Mr. Kruse, the chief engineer of Messrs. J. & W. Stewart, and Mr. Robertson, an assistant engineer, were present. The following results were obtained :—

Time.	No. of blows.	Actual Set in 16ths in.	Set by Auto Curve in 16ths in.	Elastic Recoil of Pile : 16ths in.
p.m.				
2.59	1	13	13	9
3.02	1	13	13	7
3.04	1	14	14	6
3.06½	24	—	—	—
3.14	1	6	6	5
3.18	1	4	3½	7
3.23	1	4	3½	6
3.27	31	—	—	—
3.29	1	—	—	—
Totals ...	62	54	53	40

The total error of six blows was thus only $\frac{1}{16}$ in. or a mean of − 1·85 per cent.

In regard to the rate of falling of the pencil, it was only $\frac{1}{21}$ that of a body falling freely from rest, while the motion of the pile was vastly greater ; of the order 1 in. in $\frac{1}{100}$ sec., so there was not the slightest chance of the pencil drawing a plain horizontal line as Mr. Mitchell feared.

The top end of the spring moved down suddenly with the pile, but the upward pull of the spring on the weight was thereby only partly removed, as both the theory given in the paper and the curves showed, *e.g.*, suppose the elongation of the spring by the suspended weight was 6 ins., then when the top end of the spring suddenly moved down 1 in., the spring was still extended 5 ins., and thus maintained a very considerable upward pull on the weight, which had proved sufficient nearly to counteract the effect of gravity.

COAL TUBS.

By Henry Adams, M.Inst.C.E., Past-President.

Some apology may seem necessary for offering a communication to the Society of Engineers upon a subject of such apparent simplicity, but the tendency of the age being to specialisation, a monograph upon one particular thing is likely to be more complete and of more value than a general description of many things. A coal tub is the appliance hung from a crane chain which is used for lifting coals from the hold of a ship or barge and transferring the same into other craft alongside, or into a coal store, or to the heap on a wharf, or into trucks or shoots. The coal tub is known in different districts by various other names, as tank, bucket, corf, skip and skep. The earliest mention of the name of tub in this connection appears to be in an Act of Parliament passed in the year 1679 relating to the measurement of the craft used for carrying coals on the River Wear and prescribing that always, in measuring these river craft, should be used " the Bowle Tub of Newcastle, containing $22\frac{1}{2}$ gallons Winchester measure," and to prevent overloading " allowing 21 bowls of coals to be measured by such Bowle Tub by heap measure and no more." There was no Plimsoll mark in those days, and 200 years later it was to a coal merchant (Samuel Plimsoll) that the mercantile navy owed that most useful check against overloading.

Now the Winchester bushel contained 2,150·42 cubic inches, so that a Winchester gallon would be $\frac{2,150 \cdot 42}{8} = 268 \cdot 8$ cub. in., and $22\frac{1}{2}$ Winchester gallons would be $\frac{268 \cdot 8 \times 22\frac{1}{2}}{1,728} = 3 \cdot 5$ cub. ft. as the capacity of the " Bowle Tub of Newcastle." The heaped Imperial gallon exceeded the striked Imperial gallon in the ratio of $\frac{351 \cdot 936}{277 \cdot 274} = 1 \cdot 27$ to 1; assuming the heap measure of the tub to be in the same proportion the maximum capacity would be $3 \cdot 5 \times 1 \cdot 27 = 4 \cdot 445$ cub. ft., which at 45 cub. ft. to the ton would be as nearly as possible 2 cwts. of coal. With 21 of such bowls the craft would contain 42 cwts. or 2 tons long measure. In 1668, according to Defoe, above 100 ships belonging to Ipswich were engaged in carrying coals from Newcastle to London " the least of which carried fifteen score, as they compute it, that is 300 chaldron of coals." In 1720, he says, referring to the size of ships built at Ipswich, " I appeal to the Ipswich colliers (those few that remain) belonging to this town, if several of them carrying seventeen score of coals, which must be upward of 400 tons, have not formerly been built here . . . . " By old tables of weights and measures a barge or keel of coal was 424 cwt. = 21 tons 4 cwt. and 20 keels or 424 tons made one ship load.

The origin of the term chaldron is doubtful, but 1 ton of coal makes 1 chaldron of coke, which has an average weight of 13½ cwt., or 1½ chaldrons of coke weigh 1 ton. The volume of 1 ton of loose coal averages 45 cub. ft., 1 ton of coke averages 75 cub. ft. A 2-cwt. coal sack contains 4½ cub. ft. If 1½ chaldrons of coke weigh a ton and measure 75 cub. ft., a chaldron must contain 50 cub. ft., and if filled with coal would hold an average of $\frac{1 \times 50}{45} = 1\frac{1}{9}$ tons or $22\frac{2}{9}$ cwt. Seventeen score would be $17 \times 20 = 340$ chaldrons, and $1\frac{1}{9} \times 340 = 377\frac{7}{9}$ tons, so, if this calculation is correct, when Defoe says it " must be upward of 400 tons " we must allow a little for " journalism." But there is some doubt about it because by a statute of Charles II. a chaldron was equal to 36 coal bushels or 25½ cwt., but customarily in England equal to 32 heaped bushels. At 25½ cwt. to the chaldron, 340 chaldrons would weigh $\frac{340 \times 25 \cdot 5}{20} = 433 \cdot 5$ tons, so Defoe may have been right after all. The " Newcastle chaldron " is given in *The Century Dictionary* as 52½ or 53 cwt., and the United States chaldron as 26¼ cwt. but varying in the other American ports. A standard bushel (used for many purposes as " dry measure ") contains 2,218·192 cub. in., 36 striked bushels would thus be $\frac{2{,}218 \cdot 192 \times 36}{1{,}728} = 46 \cdot 2123$ cub. ft., and if heaped as with coal or coke would probably exceed 50 cub. ft. By the Weights and Measures Act of 1889, all coal must be sold by avoirdupois weight.

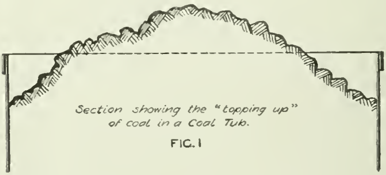
In 1860 the steam ships (screw colliers) bringing coal to the port of London, averaged perhaps 750-ton cargoes ; by 1890 the average had increased to about 1,000 tons, although several reached 2,000 tons. During the same period the barges on the Thames increased from 60 tons burthen (largest in 1860) to 140 tons.

Coal will run down a metal shoot at a slope of 6 inches in 1 foot, or 26½ degrees, and down screen bars at a slope of 9 inches in 1 foot, or say 36 to 37 degrees, according to the size and dryness of the coal. Ordinary screens slope 36 degrees ; the bars are 1½ in. deep, $\frac{11}{16}$ in. thick at top edge, $\frac{5}{16}$ in. thick at bottom edge, and ⅝ in. apart. Screens for small coal slope 37½ degrees ; the bars are 1¼ in. deep, ½ in. tapering to ¼ in. thick and ⅜ in apart. Screen bars are usually 6 ft. long, supported top and bottom and at the centre. Rarely they are made 9 ft. long and supported at intervals of 3 ft. The gauge is kept by the use of distance washers. Coal should never be tipped direct on to the screens but on to a dead-plate of the same slope, at the higher end. In the bad old days the " workhouse shutter " was a solid wooden shutter temporarily placed behind the screen bars while coal was being run down the screen (and ostensibly being screened) in the presence of the Inspector sent by the local Board of Guardians. This was preceded by a private interview with the firm which did not tend to make his eyesight keener, but he could swear he saw the whole of the coal pass over the screen.

The pressure on the side of a bunker at any point is say 12 lb. to 18 lb. per square foot per foot head, according to whether house coal or Welsh coal is stored, but it should be calculated, from the natural slope and the weight of the particular class of coal, the same as a retaining wall, for a depth of twice the least width, but beyond that the side thrust will not increase, owing to the holding up power of the friction against the sides. For coal stores, pockets, bins, bunkers, silos, cells or hoppers, as they are called by various persons, the usual allowance is 45 cub. ft. per ton, or 50 lb. per cub. ft., but the Navy allowance for bunkers is 48 cub. ft. per ton. The actual weight of coal as brought by rail or ship, and the angle of repose or natural slope, are as follows :—

	Lb. per cub. ft.	Angle of repose.
House coal...	50–55	36–40°
Gas coal	56–58	36–40°
Welsh coal...	70–75	36–40°
Coke	25–35	35–45°

The " topping up " of the coal in a tub is shown in Fig. 1, the margin left at the sides is about equivalent to the piling up in the centre, so that the full net capacity is utilised. In reality the topping up is much more irregular, often a piece weighing ½ cwt. or more will be put on last of all leaning against the bale.



Section showing the "topping up" of coal in a Coal Tub.

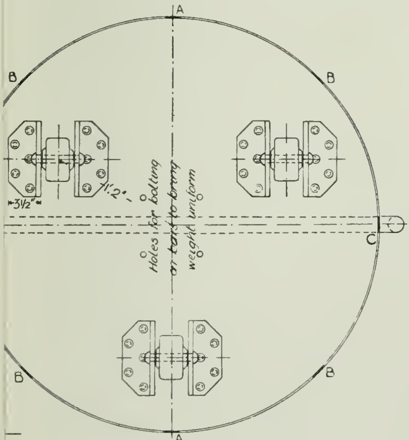
FIG. 1

)AL TUB_ STEEL
45 CUB. FT.

t

23cwt., Ballast 38cwt., Gas coke 11cwt., Hard coke 15cwt.

N°6 B.W.G. 3.0"x10¼", Bottoms N°4 B.W.G. 3.' 7½" diam.
"x½", Remainder of fittings Wrot. iron
ning ring, which are ½" diam., pitch as shown, lap 1½"
war cost £12
s marked A
" B
o cover) " C



PLAN ON UNDERSIDE

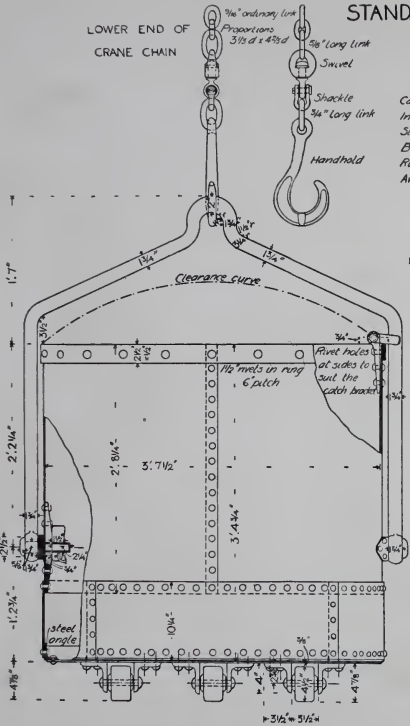
STANDARD PATTERN_18 CWT. COAL TUB_STEEL

NETT CAPACITY 34·845 CUB. FT.

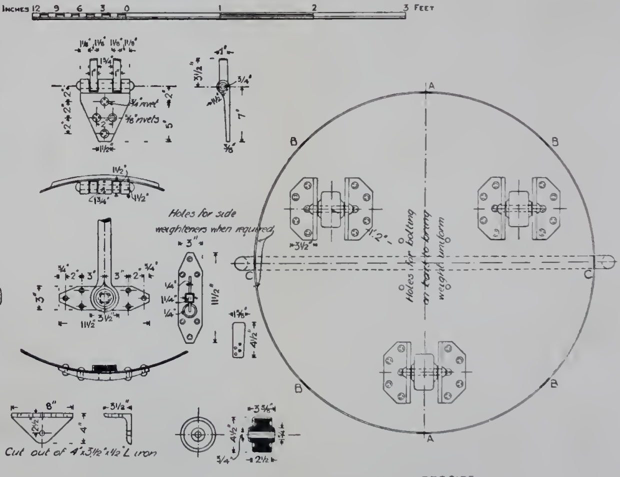
Scale_1½ inches to 1 foot

Capacity_House coal 16 cwt., Gas coal 18 cwt., Welsh coal 23 cwt., Ballast 38 cwt., Gas coke 11 cwt., Hard coke 15 cwt
Inside dimensions, diameter 3′. 7½″, depth 3′. 4½″
Steel plates, Upper tier Nº B.W.G. 5′.10″ x 2′.8¼″, Lower tier Nº 6 B.W.G. 3′.0″ x 10¼″, Bottoms Nº 4 B.W.G. 3′. 7½″ diam
Bale (steel), diam. 1¾″ to 2″, Stiffening ring (steel) 2½″ x ½″, Remainder of fittings Wrot. iron
Rivets all ⅜″ diam. except in wheel brackets and Stiffening ring, which are ½″ diam., pitch as shown, lap 1½″
Average weight complete = 5 cwt. 3 qrs. 0 lbs. Pre-war cost £12

Joints in upper tier of plates marked A
Do. " lower " " " " B
Do. " Angle iron (plain butt, no cover) " C



FRONT ELEVATION


INCHES 12 9 6 3 0 1 2 3 FEET
1⅛″ 1⅛″ 1⅛″ 1⅛″
1¾″
¾″ rivet
⅜″ rivets
5″
3½″
1″
¾″
7″
⅜″
1½″
1¾″
4½″
Holes for side weighteners when required
3″
2″ 3″ 3″ 2″
11½″
3½″
1¼″
11½″
1⅜″
4½″
8″
3½″
4″
Cut out of 4″ x 3½″ x ½″ L iron
3¾″
4½″
2½″
¾″
A
B
B
C
C
B
B
A
1′.2″
3½″
Holes for bolting on tails to bring weight uniform

DETAILS

PLAN ON UNDERSIDE

The tubs are never filled fully to the margin, as some heavy pieces might roll off on to the heads of the men working below while the tubs are being lifted out of the ship's hold by the cranes.

Welsh coal is the most awkward to deal with, as it is not only very heavy, but it is also irregular in size and very dusty. The average capacity of coal tubs with ordinary topping up is for :—

	cub. ft per cwt.		lb. per cub. ft.
House coal	2·19	equivalent to	51·14
Gas coal	1·94	„	57·73
Welsh coal	1·52	„	73·68

Nominally the capacity is taken as 2 cub. ft. per cwt., or 40 cub. ft. per ton, but when any particular class of coal is to be dealt with its actual weight should be taken into account. The specific gravity will not give this as the weight of a given bulk will vary with the size and shape of the pieces into which it is broken.

The first coal cranes worked by hydraulic power were erected in 1851 at the Poplar Dock of the North London Railway Co., for the Northumberland and Durham Coal Co., who leased the premises. The cranes were simple raking jibs or derricks lifting 10 cwt. of coal in tubs out of the ship's hold, after which they were tipped into railway trucks on the quay in front of the crane house. Some swinging cranes, 21 ft. radius were erected at the Limehouse Basin of the Regent's Canal Co., in 1854, and similar cranes in 1856–7 at Charrington's Wharf. The full lifting power was 14 cwt., viz., 10 cwt. of coal and 4 cwt. weight of tub. Some steam cranes were in use before this time with tubs weighing 3½ cwt. and lifting 3½ cwt. of coal. The dimensions were gradually increased as time went on. In 1877 the tubs had reached 15 cwt. capacity with a weight of 5½ cwt., and the cranes 26 ft. radius ; in 1890 the tubs had reached a capacity of 23 cwt. of Welsh coal with a weight of 5 cwt. 3 qrs., and the cranes had a lifting power of 30 cwt. It will be seen that the dead weight of the tubs varied from about 45 lb. per cwt. capacity in the earliest forms to 28 lb. in the latest, while the cost of repairs has been greatly reduced owing to the more skilful placing of the material in the design. A coal tub is not a piece of mechanism that can be properly designed from general principles alone. It requires a long practical experience to find out the weak points and to arrange the details so that the tubs can be used with the maximum of convenience and safety and the minimum of cost and delay in repairs. Every part is liable to damage but more particularly the bale may be bent, the top stiffening ring of tub broken through a rivet hole, or a wheel knocked off through careless handling when loaded. The maximum corrosion occurs round the lower 6 inches of the inside of tub, owing to moisture there in the small coal caked in the angle during wet weather. For this reason a narrow tier of plates is adopted round the bottom to leave smaller pieces to cut away for repairs. The wear and corrosion together reduce the weight of a tub about 2 lb. per month, and as the tubs have to be kept to a standard weight for uniform "tare," pieces of iron called "weightners" have to be bolted on. These are generally pieces of flat bar iron 3 in. × ½ in. to 4 in. × ¾ in. weighing 10 lb. or more, with standard spacing for the bolt holes. As the coal tub has to tip easily when loaded, as soon as the bale is released from the catch, and has to right itself readily as soon as the coal is shot, the balance of the tub must not be greatly disturbed. The first weightner added will be attached to one side or to the bottom according to which disturbs the balance least. The same principle regulates the addition of other weightners until perhaps there may be 40 lb. so fixed. In making a set of new tubs the plates are sorted so that the tubs are practically of uniform weight, *i.e.*, within ½ per cent.

The writer had for many years the supervision of three-fourths of the coal cranes in the port of London and was occasionally connected with the remainder, so that he had good opportunities for studying the question of coal tubs under all conditions. The outcome of his experience was the design of the coal tub shown in Fig. 2. It was evolved by slow degrees after the trial of other modifications during the course of delivering overside twenty million tons of coal, and it is believed to combine the maximum of strength and durability with the minimum of cost, *i.e.*, including both first cost and maintenance. The bale is of uniform diameter except that it is "jumped up" or swelled at the centre where the wear of the hook affects it most. The shape of the crane hook and method of connection are different at almost every wharf, but the arrangement of the hook and lower end of crane chain shown here was found to give the best results in working.

Coal tubs are still largely used in London and elsewhere, but as they require to be filled by the "coalies" with shovels in the ships' holds, the labour troubles of the last 30 years have brought about an increasing use of automatic grabs, which can be lowered by the crane into the ship's hold and bring up a ton of coal at the time. The empty grabs weigh from 30 cwt. to 2 tons each, so that the expenditure of power in lifting this dead load brings down the efficiency of the machinery and adds considerably to the cost. "Trimming" in the hold is also required to bring the coals from the corners to the grab, when the bottom is cleared under the hatchway, but two men in the hold instead of eight enable the work on the whole to be done at less cost and with less risk of delay.

Monday, October 2, 1922.

A. Stewart Buckle, M.I.C.E., Vice-President,

in the Chair.

THE ECONOMICS OF ARTERIAL LAND DRAINAGE.

By C. H. J. Clayton, M.Inst.C.E., M.S.E., F.G.S., Chief Engineer, Land Drainage and Reclamation Branch, Ministry of Agriculture and Fisheries.

"Land Drainage" is a comprehensive term which covers a wide variety of operations all or any of which have one object, viz.: That of discharging to sea surplus water from the land.

Every agriculturist knows that efficient drainage is essential to the successful cultivation of the soil, but it does not follow that agriculturists generally are fully appreciative of the extent to which works of engineering may be necessary in order to remove from the wide areas comprising the valley lands of a given river system that proportion of their water content which is unessential or injurious to agriculture. Such works may include the improvement of tidal outfall channels: the re-sectioning, re-grading and sometimes the diversion of main river channels: the formation of new arterial drains: the construction of tidal and other embankments: the erection of tidal and other sluices: the provision of pumping plant and many incidental works which would not normally come within the purview of a purely agricultural community.

The main objects of the drainage of agricultural land are to discharge surplus water from the land so that moist, as distinguished from wet, soil may be left for the healthy penetration and feeding of the roots and root fibres of plants and for the freer admission of air to the soil: to improve the texture of the soil by setting it free to benefit by the contractive and expansive influence of alternations of temperature and the penetrative activities of earthworms: to stimulate by aeration the decomposition and assimilation of mineral and organic substances either in the soil or in the fertilisers applied to the soil and so to increase the heat permeability of the soil that it may receive earlier and retain later the "growing" temperatures of summer.

If surplus rainfall cannot be carried away either by the subsoil or by means of drains and ditches, it will be likely to accumulate until the level of saturation may be so near the surface as to render cultivation hazardous or hopeless. If, the water can pass freely through the soil and the surplus be passed away, the upper soil will be beneficially irrigated, and frost, air and heat, will have freer scope as disintegrating, sweetening, and germinating agents.

Owing to the more open texture of well-drained soil, summer rains are rapidly absorbed ; the water is thus conserved against evaporation or surface discharge. During the growing seasons, rootlets are able to traverse the soil in all directions in search of nutriment and moisture, whilst the warmth of the sun, the salts of the earth and the nitrogen of the air may find free play in a soil which is open to physical and chemical combinations of advantage to plant life.

It has been abundantly demonstrated that fertilising agents are more efficacious on well-drained than on ill-drained land ; their nutritive and restorative properties are usefully employed instead of being dissipated in the sodden soil. Smaller quantities, therefore, are needed and better results are obtained for the quantities applied. Owing to the much wider range from which the roots and root fibres can draw moisture and nutriment, well-drained land is far more suitable than ill-drained land to support plant life during periods of drought. In ill-drained land the water may lie upon or just below the surface for injuriously long periods, so sealing up the interstices of the soil against the admission of air and warmth, drowning out its aërobic life ; lowering its temperature and souring it generally.

In an introductiry Leaflet issued by the Ministry of Agriculture and Fisheries shortly after the passing of the Land Drainage Act, 1918, and circulated throughout the country, the following words occur :—

> " There are estimated to be in England and Wales something like a million acres which, by the improvement of arterial drainage, might be either brought into arable cultivation or greatly increased in value as grass land. Private efforts having in view the prevention of floods and the more efficient drainage of agricultural land have often been attended by little success, as the endeavours of energetic owners and tenants have been neutralised by the failure of others to carry out work essential to proper drainage, and difficulties have arisen in securing combined action by the whole of those concerned. In many places Commissions of Sewers have been established for centuries ; in others, drainage authorities have been constituted under local Acts ; and a number of Drainage Boards have been set up under the Land Drainage Act, 1861. The total area dealt with is, however, small compared with the large area of floodable and waterlogged land capable of improvement. In many instances also, the drainage districts have been formed with a view to isolated areas and without any provision for co-ordination between the drainage authorities exercising jurisdiction in the same river basin."

In the course of a letter dated November 19, 1918, covering that Leaflet, the Ministry said :—

> "Owing to a variety of causes, the channels (both natural and artificial) carrying the arterial drainage of agricultural land have, in many parts of the country, lapsed into such a condition that they are no longer capable of efficiently discharging that function. The experience gained by the Ministry in the course of carrying out their policy of increased food production, necessitated by the pressure of war conditions, has shown that a considerable improvement in arterial drainage is urgently necessary in order that a very large acreage of potentially good arable and profitable pasture land may not continue to remain derelict or semi-derelict with a resultant loss of food to the country and of revenue to the State and to Local Authorities. The improvements required vary in different districts. Some areas require more or less elaborate schemes involving the expenditure of a considerable amount of money and a large supply of labour, or need the provision of machinery for pumping or other purposes. These cases could not, for obvious reasons, be dealt with during the progress of the War, but in many other instances it was shown that the application of a relatively small amount of labour, rightly directed, would at once set free a considerable acreage for the production of food and a great deal of good work has been done in this direction by the Agricultural Executive Committees acting on behalf of the Ministry under the Defence of the Realm Regulations."

The war policy of increased food production referred to in the Ministry's circular letter included orders requiring the ploughing out of very large areas of old grassland and the sowing of the broken areas with cereals and other human food crops. Very early in the application of this part of the policy complaints were received from many counties that the prescribed quotas could not be met on account of the liability of large areas of the scheduled lands to flooding or waterlogging, and it became the duty of the author to visit the districts in respect of which the most serious complaints were received and report upon the possibility of emergency works for the relief of the affected lands. Where such works were decided upon orders for their prompt execution were issued by the County Agricultural Executive Committees acting under powers conferred by the Ministry under the Defence of the Realm Regulations known as 2. M. In most instances the frontagers upon whom orders were served preferred that the Committees should themselves carry out the works and apportion the costs among them, and that, in fact, was done in nearly every case.

Among the works which were carried out during 1917 and 1918 by the Agricultural Committees with the aid of German Prisoner labour the following may be cited as instances :—

The Bellasize Drain which taps an area of about 4,000 acres in Howdenshire on the north side of the Humber and which was said not to have functioned properly for about 70 years was thoroughly cleansed, re-sectioned and regraded at a total cost of about £1,200. Much of the land which had been uncultivable was ploughed and sown and the remainder greatly improved for the feeding of stock. The author thinks it is fair to suggest that the average annual increase in the productivity of the land is not less than £2 an acre, which would show an exceeding handsome profit upon a capital outlay of about 6s. an acre.

The West Moor and Park Drains, near Doncaster, which had been totally neglected for over 30 years were similarly treated at a cost of £1,365, and released for active agriculture 4,027 acres of good peat land which had not for a generation produced anything but rough grazing. By the time the work was completed the saturation level in the land had gone down from an average depth of 6 in. to an average depth of 30 in. below the surface and, even before completion, some 1,200 acres were ploughed and sown with potatoes, oats and market vegetables. Here again it is not unreasonable to assess the increased productive value at £2 an acre annually for a capital outlay of only 6s. 8d. an acre.

In the Tickhill area, West of Doncaster, 2,950 acres were similarly improved for agriculture at a cost of only £365. In this case the increased annual productive value was about £1 an acre against a capital expenditure of about 2s. 6d. an acre. Other cases in Yorkshire were at Thorne, where 13,200 acres were improved at a cost of £2,700, say 4s. an acre; Gowdall, where the area treated was 700 acres at a cost of 3s. 6d. an acre; Don Valley, where an area of 40,000 acres was enormously relieved by the clearing out of a short congested length of the river at a cost of £500 or about 3d. an acre. An even more ridiculously low cost was shown in the Torne Valley, where about 2,000 acres of good land was chronically waterlogged; the open drains intersecting the lands were almost bank high with water which, of course, prevented any discharge by the underdrains. The land was practically derelict.

The cause of the trouble was by no means apparent; but a careful investigation revealed the fact that in order to prevent the slipping in of the shaky abutments of a bridge, the highway authority had, at some time previously, built a masonry strut across the river bed. This acted most effectually as a dam, holding up the water almost to the surface level of the lands on the upstream side. The existence of the dam could hardly have been suspected by the owners of the injured lands, as the author was informed by an officer of the Land Valuation Department who knew the district well that they would have been glad to dispose of any of it for about £10 an acre. After the dam was removed the water level dropped about 28 inches, and after the lapse of a few months, when the soil had dried out, most of the lands which had previously been quite useless, became cultivable. The cost of this work was £17, or about twopence an acre on the lands reclaimed for agriculture. Probably few of the owners concerned would now be willing to accept less than £50 to £60 an acre for those lands. Similar work was done at Isleham Fen and in the valleys of the Mel, Granta and Bourne in Cambridgeshire: in the Valley of the Ivel in Bedfordshire; at Cholsey in Berkshire; on the Birkett and Gowey, and at Frodsham in Cheshire; on the Waveney and Burn in Norfolk—on the Alt and Douglas in Lancashire, and at various places in Flintshire, Merionethshire, Carnarvonshire, and many other English and Welsh Counties.

There were in all about 270 cases in which areas ranging from a few hundreds to over 40,000 acres were either rendered cultivable, or greatly improved for grazing, at costs which nowhere exceeded 10s. an acre and where, at a very moderate estimate, the increased annual value of the lands for productive purposes must at least have equalled the capital outlay. It may be objected that these low costs were a result of employing prisoner labour and that had ordinary labour been employed the costs would have been higher. The answer to such an objection is that the War Department charged for the men's services at current agricultural rates so that as regards wages there was no difference. As regards output I am bound to admit that the prisoners, as a whole, did more work than I should have expected from ordinary labourers; probably for the reason that they were working under a discipline which did not encourage slackness.

So far, the author has mentioned only instances of the improvement of areas which are more or less remote from the outfalls of the drainage systems of which they form part, and in some cases at a distance from the main arterial channels which must take their water to sea. It must be obvious, however, that the permanent redemption of these and similar lands can only be effected by so improving the arterial systems that the whole of the lands which depend upon those systems for the discharge of their surplus water to sea shall be freed from the danger of waterlogging and rendered safe against any but extraordinary floods.

The improvement of upstream areas, although nearly always practicable and, perhaps, justifiable, as an emergency measure, or in circumstances in which larger works could not be conveniently undertaken, offers no permanent cure for ills which may affect the system as a whole ; indeed, one has to recognise that to remove the blockage from a large area of waterlogged land and release the water into an unimproved river system will result simply in a transference of the trouble from a higher to a lower portion of the same valley. It is open, of course, to anyone who can manage to do so to discharge surplus land water into a river, irrespective of the capacity of that river to carry the water to sea, but it is obvious that if every owner within a given river system were to avail himself of his rights in that direction before the main arteries had been put in order the last condition of the lower levels would be worse than the first.

Land drainage works, to be fully effective, must begin at the sea outfall and proceed upward. The main requirements are that the freest possible flow and ebb conditions in the tidal outfall channel shall be obtained so that the regular flux and reflux of the tidal wave may operate to the best advantage for scouring purposes and that the lowest possible ebb level may be secured at the upstream tidal limit. Above that limit, river sections and gradients should be improved where necessary in order that the mean velocity of ordinary flows may vary as little as possible from their extremes and that flood flows shall find accommodation between banks at sufficient distances apart and of sufficient height and strength to prevent the flooding of the flanking lands. Where milling, navigation, or fishery interests are encountered, floodgates, weirs or tumbling bays may need to be improved in capacity, and arrangements made for the prompt drawing of floodgates at spate periods. For these purposes it would be necessary that the whole of the arterial system throughout its ramifications from low water at sea to its upstream limits should be administered for drainage purposes by a single authority having power to make regulations and enforce their observance. It will be recognised that in the present neglected condition of most of the great river systems, the physical requirements would be large and very costly ; that in order to achieve a reasonable measure of success, there should be a sufficiently large rating area to bear the expense without distress and that a comprehensive works policy should be laid down at the outset. Subject to certain statutory provisions for the protection of the interests of the ratepayers, the drainage boards have full authority to carry out works and to rate the lands for their cost and maintenance, but it remains to be seen to what extent the newer authorities will recognise the opportunities open to them of making agricultural history within their areas of jurisdiction. Those which have been established since the Act was passed have not had much time for investigation of the actual position and it is hardly likely, therefore, that the larger of them have yet adopted a comprehensive works policy.

The author is afraid that the Ministry's reference in the letter above quoted to the urgent necessity of improvements in Arterial Drainage was not so stimulative as it might have been if prices had been normal. Drainage authorities were rather apprehensive that the cost of any capital works which might have been undertaken at that time would be prohibitive and, indeed, the author has some reason to believe that even under more normal conditions such authorities do not always consider, in sufficient detail, the question of benefit against cost. One is sometimes asked, " Well, what is it going to cost ? " and if the answer is in tens or hundreds of thousands, the figures alone appear to cause serious alarm and the case is prejudiced from the outset. The points to be emphasised are that the total cost of large works is expended over a period, perhaps of years ; that it need be raised only as it is required and that repayment may be spread over periods of from 15 to 30 years according to the character of the work. A few simple calculations on this basis would, in most cases, suffice to show that an alarming looking estimate is reducible to an annual drainage rate of a few shillings an acre.

During the passage through Parliament of the Order establishing the Ouse Drainage Board there was considerable opposition from certain local authorities, whose counsel sought to show that the cost of works would be absolutely ruinous to areas in which their clients were interested. The parliamentary committees were unconvinced and the Order went through, but it is not certain that the principal opponents of the Order have even yet sat down with the estimates and schedules and calculated what the incidence of rates would be. That it would not be ruinous, the author may be able to show.

In 1917 Mr. A. Havelock Case, M.Inst.C.E., prepared for what was then the Lower Ouse Drainage Board a complete scheme of works and estimates for the improvement of the tidal section of the River from its outfall into the Wash, below Kings Lynn, to Denver Sluice, a distance of about 16 miles. In 1917 and 1918 Mr. R. F. Grantham, M.Inst.C.E., prepared for the Ministry of Agriculture and Fisheries estimates for the cleansing, re-sectioning and re-grading of the tidal channel known as the Hundred Foot River between Denver sluice and Earith, and for similar treatment of the nontidal channels of the Ten Mile and Old West rivers and their tributaries, also between Denver sluice and Earith.

No regular survey which would furnish the basis of an estimate of the cost of works above Earith has been prepared so far as the author is aware, but it would not be difficult to arrive at a reasonable average figure per mile of length and, knowing that part of the river pretty well, he does not think he need hesitate to add a lump sum to whatever the other sums should be after making allowances for the difference in prices since the estimates were made.

The substantive estimates are as under :—

	£	£
Mr. Case's estimates (*1917*).		
Extending training walls into the Wash	335,000	729,500
Raising and repairing existing training walls	15,000	
Dredging outfall channel	20,000	
Cutting off Magdalen Bend (including purchase of 24 acres of land at £100 per acre)	36,500	
Deepening and widening river below Denver	310,000	
Dredging in Eau Brink Cut	13,000	
Mr. Grantham's estimates (*1917 and 1918*).		
Dredging and widening channel and improving banks of the Hundred Foot River	175,000	437,000
Similar improvements to the Ten Mile River, Old West River and the tributary rivers Wissey, Brandon, Lark and Cam	262,000	
		1,166,500
Add for increased cost since dates of estimates (assuming that works would take 10 years to complete) at 75 per cent.		874,875
Author's rough estimate (*1922*).		
Improving channels and embankments of main river and principal tributaries above Earith, including modifications of disused locks and mill sluices, weirs, etc.		130,000
		2,171,375
Acquisition of land, parliamentary, law and engineering charges at 7 per cent.		151,996
		2,323,371
Say		£2,324,000

That is, of course, a very alarming looking estimate. It may be interesting to see how it works out in relation to the half million acres which would have to bear the charges. It is clear that so large a programme of works could be carried out only during a period measured by years, and the author does not think it would be safe to assume that in ordinary circumstances the system could be got into order in less than seven years. If it be assumed that a ten years' works policy were adopted; that the total expenditure might be spread equally over that period, and that the money were raised by equal annual loans, such loans to be repayable by annual instalments of principal and interest over 30 years, the position would be as under :—

Amount of Loan.		Sinking Fund and Interest at £6 9s. 5d. %			Average Rate per acre on 500,000 acres.	
	£	£	s.	d.	s.	d.
1st year ...	232,400	—			—	
2nd ,, ...	232,400	15,038	4	4	0	7¼
3rd ,, ...	232,400	30,076	8	8	1	2½
4th ,, ...	232,400	45,114	13	0	1	9¾
5th ,, ...	232,400	60,152	17	4	2	5
6th ,, ...	232,400	75,191	1	8	3	0¼
7th ,, ...	232,400	90,229	6	0	3	7½
8th ,, ...	232.400	105,267	10	4	4	2¾
9th ,, ...	232,400	120,305	14	8	4	10
10th ,, ...	232,400	135,343	19	0	5	5¼
11th ,, ...	—	150,382	3	4	6	0½

Total loans, £2,324,000

The sinking fund and interest would continue to be at the rate of 6s. 0½d. an acre per annum from the 11th to the 31st year, after which the rate would drop by 7¼d. an acre per annum until the 41st year, when the debt would be extinguished. As to the cost of maintenance of the new works the author suggests that this would not begin to become an appreciable charge much before the end of the 5th year, but that from that period onward, say until the 20th year, an average rate of 6d. an acre, producing £12,500 per annum, might suffice. Maintenance costs would, of course, show a tendency to increase with time, and it might be that the rates for that purpose would ultimately rise to an average of 1s. an acre, or £25,000 p.a.; but it is hardly anticipated that that figure would be reached until the loans for the capital works had been almost extinguished. If these figures are reasonable we should have at the end of the 5th year a rate for capital works and maintenance of 3s. 6¼d., rising by 7¼d. annually to 6s. 6½d. in the 11th year, and continuing at that figure until the 31st year, after which the cost of works would fall by 7¼d. an acre whilst the cost of maintenance might possibly rise by stages from 6d. to 1s. an acre.

The calculations refer, so far, to the average rates payable over the whole area. It should be stated that that area of half a million acres is divided by schedule into a considerable number of areas and sub-areas for purposes of differential rating. Some areas therefore will pay more, and some less than the average, in accordance with the degrees of benefit to be derived from particular works. Thus an area of 25,000 acres immediately above Earith (Sub-area A9 in the Schedule to the Act) would be called upon to contribute about £59,000 out of a total of £1,600,000 for works in the main channel below Earith. This contribution works out at an initial rate of about 3½d an acre, and a maximum rate of 3s. an acre, or about one-half the average.

It is not unfair to suggest that if the works achieved the objects for which they were designed, opportunities for economies in other directions would present themselves. For example, if one of the effects were to secure a lower low water level in the tidal compartment of the river, the non-tidal portions of the river system and the artificial drains emptying into them would get longer and better discharges and therefore lower average levels. This would probably result in reduced costs for the upkeep and repair of banks, and should certainly tend to lower the expenses incidental to pumping. It is manifestly impossible to calculate the value of such economies, but whatever their annual value might be, that sum should, in fairness, be put on the other side of the account. If one may be permitted to hazard a guess, and put these savings at an average as low as 10d. an acre per annum, we should have, say, from the 11th year to the 31st year, a net maximum charge fluctuating between 5s. 8½d. and 6s. 2½d. an acre, after which the charge would drop by 7¼d. per acre per annum to a few pence representing the difference between maintenance and internal economies. It might not be useful to attempt to compare the various values for productive purposes of lands comprising so large an area as half a million acres, but it is fair to suggest that the present average yield of the whole might be increased by a good deal more than the annual charges represented by these estimates. There would, of course, be local and sectional charges within the area, such as those for internal works and administration ; but these would be equally payable whether capital works upon the main arteries were carried out or not, and the author has ventured to suggest that for internal works, at any rate, they are higher now than they would be if the capital works were carried out. His main purpose is to show that, from the point of view of increased production of foodstuffs a large capital expenditure on arterial drainage works in a large area may be as justifiable and profitable as a small expenditure has been shown to be in many a small area. The author must leave to economists, and taxing and rating experts, any calculation of the secondary financial consequences of largely increased production over wide areas; but he suggests that the food consuming public and the local and imperial authorities would be gainers by the larger volumes of supplies and the generally increased prosperity of the affected areas.

No one who is interested in agriculture can but deplore the waste areas which are observable by all who traverse the country either by rail or by road. It is impossible to travel any considerable distance without noticing wide areas of potentially good land at present producing nothing but rushes and rank grass, but which might be either turned into good pasture or, better still, broken up for the cultivation of grain and other human foodstuffs. The root cause of these manifestations is never very far to seek. Somewhere near these lands there is a watercourse whose normal water level is too high to permit of the successful drainage of the affected areas. Nothing that local farmers or owners may do can be effective until that excess water can be got away; but that is just where the main trouble presents itself. It may be everybody's interest, but it is nobody's business to improve the watercourse and its continuations down to its sea outfall: a thousand and one interests may intervene. It was for the purpose of co-ordinating those interests and establishing authorities having a single responsibility for the whole of any given drainage system that the Land Drainage Act, 1918, was passed. The process of education may be slower than enthusiasts might wish, but there are already evidences of recognition that sound engineering works of arterial land drainage may be a handsomely paying proposition; but that, at any rate, if wet lands are to be made productive something more than local and individual processes must be applied.

The author does not know whether he has succeeded in carrying the members with him so far, but if he may venture to assume that he has made out a reasonably good case for the economy of necessary arterial drainage works, he will feel that his paper has been in some measure justified.

It has been wisely said that he who makes two blades of grass grow where one only grew before will leave the world better than he found it. The author's humble suggestion is that sound and far-sighted drainage engineering need not be satisfied with so modest an objective.

Discussion.

The Chairman, **Mr. A. Stewart Buckle, M.Inst.C.E.,** said, they had had an interesting paper on a subject that could not fail to call attention to the fact that if it was a success it was immediately wealth-producing. That is to say, that unlike railways and other remunerative engineering works, one did not have to wait for people to make use of it before one could expect to earn dividends. In the case of land drainage the land itself immediately took on an increased value by being more wealth-producing.

After all in draining land we were only carrying on and continuing the work that had already been done in past ages by the rivers themselves. An example of this that he might mention was to be seen in the Clifton gorge that carries the Avon from Bristol to the Severn Channel. This gorge must have been all cut out by the river Avon, but before it did so the basin of the river at Bristol and Bath must have been a great lake.

In the course of the discussion the Chairman remarked that Mr. Korthals Altes had stated that in Holland the high land as well as the low land was rated for the cost and maintenance of the works. He did not think that this was ever the case in this country.

At the close of the discussion the Chairman referred to works of land drainage that he had seen in Burma. Generally in works of irrigation in India it was required to bring water on to the land, but the case that he was thinking of was where there was an enormous area of land that had not been cultivated owing to the floods. A navigable canal was made through this area and, incidentally, this drained or diverted the water from above the canal and so brought all this area into cultivation, thus considerably increasing the land revenue to Government.

He had also had some experience of the constant trouble caused by the flooding of the river Lea at Waltham Abbey and Enfield Lock. A land drainage commission was formed some years ago to deal with this, but although they did a great deal, not having control of either the source or the mouth of the river, their efforts had not been successful. To add further to their difficulties the River Stort, one of the main tributaries, had been dredged and made navigable, thus throwing the water down to the valley much quicker, and lower down the Metropolitan Water Board had filled the valley with a series of Reservoirs, the last being King George's Reservoir. The result was a succession of record floods during the war. Nothing appreciable has yet been done to remedy this state of affairs.

Mr. J. Korthals-Altes, F.R.G.S., said, as a Dutchman, and knowing history well, he knew how brave the English were, but of all the brave Englishmen he considered the author of the paper, Mr. C. H. J. Clayton, the bravest, the reason being that in every country, it might have been Holland, England, Germany, France, even Iceland, where he had been this Summer, he met farmers and came, in each country, to the same conclusion—farmers were the most conservative people in the World.

To advocate a proposition, which meant money out of the pocket of farmers, and especially in these days of great agricultural difficulties of malaise, was a feat of great courage, even when it was promoted in such an admirable way as by the author.

Mr. Clayton had shown us so well how necessary it was to improve the condition of the soil by means of drainage, but he was afraid that his excellent proposition would not be encouraged by the majority of farmers and landowners.

He knew something about the same question in his own country of Holland. He remembered how he tried to convince, some years ago, many neighbours, landowners and farmers, near Hulshorst in Gelderland, of the necessity of drainage of their properties by establishing a board. The opposition with which he was met was enormous. Happily he could show some excellent results in another part of Gelderland, where he and some friends had improved thousands of acres of boggy land, thanks to the creation of a drainage board—the Bexkuhe Beek—which effected the arterial drainage of an area of over 20,000 acres. The majority of farmers and landowners at Hulshorst by regarding the results obtained elsewhere, the photos showing how boggy, waste land had been transformed into excellent land with large crops on the fields and fat cattle on the pasture land, were convinced and the proposition was carried. But one old farmer who was still opposed got up and said: "It is all very well, I am sure Mr. Korthals-Altes knows something about drainage and he speaks very well and explains it nicely, and as far as farming goes he may know much about agriculture in general, but he does not know how to milk a cow." Mr. Korthals-Altes admitted he could not!

A week ago he was in Holland and he met a farmer who complained about the malaise, the bad times for farmers, but he admitted that, thanks to the fact of good drainage of their soil, he and his neighbours had still been able to make both ends meet.

He considered land drainage of the greatest importance for any country, but especially for England, where—he said it with great regret—land drainage had been neglected in a disastrous way. He had travelled through many parts of England and met often with miserable conditions of the soil, while by drainage the soil might prove to be of the best to yield a splendid crop.

The great hindrance to land drainage was the money question. Who had to pay for it?

In England it ought to be not only the owner of the *low* level who had to pay, but also the owner of the *higher* level. The latter one sent the water from his land as quickly as possible to the lower level, too quickly for the land of the lower level, which, consequently suffered through its higher levelled neighbour. The latter ought to pay for that. Besides, the necessity to bring the burden of paying the taxes for drainage on the shoulders of every landowner concerned—to the water's head—and to consider a river from the source to the outlet as one system, it would prove a question of wise policy to make one board of drainage for as large an area as possible. That would improve the drainage and diminish the expense.

This policy of larger areas had been advocated in vain for years, especially for North Holland. But he found comfort in the history of his country. Even Napoleon had failed in his endeavour to get rid of the too many drainage boards in Holland and the speaker feared we ought to regret that Napoleon did not rule one year longer in the Netherlands so as to have accomplished his task with regard to a consolidation of the drainage system. But a power stronger than Napoleon had succeeded, where men—even Napoleon—failed.

It was Nature. The floods of 1916 breaking through the dykes of the Zuiderzee, flooded a large area of fertile land, threatened even the Dutch capital, Amsterdam, and opened the eyes of many, and to day they enjoyed, in North Holland, one controlling Board for the greater part of that province.

Nature by breaking through the banks of the Zuiderzee broke, at the same time, through the banks of short-sighted conservation in drainage matters—but only then, and in that period of danger.

He had seen in Yorkshire how beautiful farms of the past were derelict for the present.

Might he draw Mr. Clayton's attention to the question of subsidence. He hoped he would look into the matter, otherwise one might lose on the left which one gained on the right.

He hoped that Mr. Clayton would continue to give his great ability in the matter of land drainage for the benefit of this country and find the great support, which he as well as the excellent work he promotes, deserved.

Mr. Arthur J. Martin, M.Inst.C.E., as a former colleague of Mr. Clayton at the Ministry of Agriculture, congratulated him and the Society of Engineers on his valuable and interesting paper.

He was especially pleased with the author's admirable statement in his opening paragraphs of the objects of land drainage. Land drainage was not merely a matter of carrying off surplus water, but of generally improving the character and stimulating the productivity of the land. He had demolished another hoary fallacy by showing that underdrainage did not result in parching the soil.

A great deal was heard just now of the expensiveness of our Government Departments. If every department of the Government did such good and remunerative work as the Ministry of Agriculture and Fisheries, the taxpayer would be fortunate indeed. Mr. Clayton had given a wonderful record of well-directed, profitable work. Investments which gave a return of 100 per cent. or more on the outlay should be good enough to tempt even the British farmer.

He (the speaker) had been personally engaged in some of the cases cited by Mr. Clayton, but mostly on inland streams which did not call for anything like the heavy outlay involved in the case of the Ouse. One point which had particularly impressed him in the course of his inspections was the wanton way in which the river was often interfered with for some petty purpose, as, for instance, by the damming of its channel to hold up water for cattle or to serve as a fence, whereby the drainage of hundreds of acres was impeded. Another point was the very small outlay required to improve the drainage of a whole valley. In many cases no engineering works whatever were necessary—nothing beyond a mere domestic clearing up and removal of petty obstructions. But even this could not be done without co-operation. Hence the need for Drainage Boards.

He trusted Mr. Clayton and his colleagues in the Ministry would persevere in the good work of breaking down the apathy which prevailed with regard to this important matter.

Mr. C. Collingwood, M.M., A.M.I.C.E., M.S.E., asked the author of the paper if one might not add to " the main objects of the drainage of agricultural land " that of the desalting of land suffering from salinity, and whether Mr. Clayton had not perhaps some information to give of reclamation of tidal lands in this country. Mr. Collingwood had experience of land reclamation work in Egypt and of irrigation work in Mesopotamia (or Irak) and could speak of the importance of keeping flat lands sweet, by securing the downward filtration of irrigation water by the inclusion in the irrigation projects of a drainage scheme also. This principle was most important, and Mr. Collingwood showed a map of such a project he had drawn up and partly carried out and which had been very favourably commented upon by the Deputy Director of Agriculture (Mesopotamia). He pointed out on the map the high level perennial irrigation canals and the course and direction of the main drains. Where the drainage was inadequate or nil in hot climates the moisture was drawn upward and evaporated, leaving, as in the case of Euphrates water, a white alkaline saline deposit which utterly ruined the land for agricultural purposes. He would not enter into details of costs as being irrelevant to work in this country, but a profit of 33 per cent. was contemplated.

Mr. Richard F. Grantham, M.Inst.C.E., F.G.S., congratulated Mr. Clayton on the excellence of his paper, and thanked him for showing how much had been done in the clearing of streams and watercourses in various parts of the country at very low cost. After 50 years' experience in the work of land drainage he was glad to be able to agree with most of the general principles laid down in Mr. Clayton's paper.

He took it that the work described had been done in the upper valleys of the rivers, but not at present in the main channels of the rivers themselves. It was patent to everyone, and Mr. Clayton foreshadowed it, that by improving the streams in the upper valleys the water in times of heavy flood would be discharged much more rapidly than hitherto, and that at the present time the channels of the main rivers were not of sufficient capacity to receive it, and that big floods would be worse and more disastrous than formerly. He had some evidence that this condition had already occurred in the Great Ouse. After the streams above Cambridge had been cleared out, Mr. Crocker, the late Engineer of the Bedford Level Corporation, had informed him that in 1918 they had had the highest flood on record at Ely. He had also received a letter stating that after the River Ivel had been cleared out, the flood water came down much more rapidly after rain, and that in 1918, at Bluntisham, they had had the worst flood on record.

Mr. Clayton stated that, notwithstanding opposition, the Parliamentary Committees, when considering the Ouse Drainage Bill, were unconvinced, and the Order went through. Unfortunately, the Committees in both Houses of Parliament did not deem it expedient to inquire into the cost of the works or the estimates or the consequent incidence of rating

The table of rating given by Mr. Clayton for the land in the Great Ouse showed an average rate of 6s. 0½d. as the cost of putting the river in order on an estimate of £2,324,000. He did not think that an average rate would represent the real incidence of the rating, but he observed that Mr. Clayton estimated the net maximum charge in the Ouse would fluctuate between 5s. 8½d. and 6s. 2½d.

In 1920 the speaker made estimates of the cost of the works in that river and its tributaries amounting to £2,367,000, approximating to Mr. Clayton's estimate. On that figure Mr. Keen, one of the most eminent of chartered accountants in the City, had worked out, according to the scale of rating in the Ouse Drainage Act, what the rates would amount to in the various parts of the valley.

The figures so arrived at were :—

	Full Rate per Acre.				
	s.	d.		s.	d.
Lands in the Fens from	1	11	to	5	8
,, Hunts., etc., Cambridgeshire	9	5	,,	12	9
	s.	d.			
,, Bedfordshire	18	5			
,, Buckinghamshire	28	5			
,, Northamptonshire... ...	29	9			

There was no getting away ultimately from these rates, as an average did not apply.

When making these calculations Mr. Keen added a footnote : " The works will take some years to complete so that the full rate " would not, in the first instance, become chargeable, but as the " cost would be raised by loan repayable over a period of, say, " 30 years, the full charge would be upon the lands for a long " period."

The reason that an average could not apply to the Ouse Valley was that the circumstances of the Fens were quite different from the conditions in the upper parts of the valley. The Fens contained a number of interior drainage districts, each with its own pumping machinery and drainage work, so that each fen had already its own drainage rates to meet. In the upper parts of the drainage district no such interior drainage work exists. These interior rates varied, according to a schedule prepared by Mr. Clayton, from 1s. 4d. to 2s., and in some cases to 6s. and 9s. per acre.

The area of the Fens is about 370,690 acres, leaving about 114,273 acres as the area of the upper parts of the drainage district as now constituted, so that, according to an average rate of, say, 6s. 0½d. per acre, the amounts of the interior drainage rate must be deducted, thus throwing a much heavier rate for the improvement of the main channel on the smaller area of the land in the upper parts of the valley. Mr. Keen's figures show accurately what the heavier rate would be when worked out on the scale of rates provided in the Ouse Drainage Act.

The Fens did not oppose the Bill in Parliament. According to the statutory scale of rates, a large part of the area of the Fens would be rated at only 1s. 11d. per acre. It is open to question whether, if it had been suggested that the contribution of that part would be raised so as to provide for an average rate of 6s. 0½d. all over the district they would have stood by without demur.

Mr. Clayton mentioned that his estimate of £2,324,000 was an alarming-looking one, but the actual cost of the works when finished would probably be still more alarming. The experienced engineers who were subsequently associated with the speaker in revising his estimate of £2,367,050 considered that he had not made sufficient provision at present-day prices, and they anticipated that the cost would ultimately approximate more nearly to £4,000,000.

The Ouse Drainage Act contains an elaborate scale of rating under which the rating increases progressively as the river rises to its source. None of the old Drainage Acts, so far as he knew, contained any such scale. Some of them provided a maximum rate as a limit. He could not help thinking that it would have been better to have omitted the scale from that Act, and have left it with the Drainage Board, who would be a large and competent body, to assess the distribution of the rate.

In most large rivers the upper valleys were narrow, so that it was impossible to expect that the lands in them can bear the whole cost of maintaining the channel of the main river. The solution of this difficulty appeared to point to the rating of the whole area within the watershed.

It was interesting to hear from Mr. Korthals Altes that the Dutch farmers, in respect of improvements by the drainage of land, were as conservative as the English farmers. After great floods there was always an outcry for something to be done to relieve the flooded land, but the moment rates were mentioned opposition was certain. Summer and dry seasons followed and the agitation ceased.

It would be only fair to point out that originally much of our knowledge of draining and embanking fens and marshes was derived from the Dutch. In the year 1626 Sir Cornelius Vermuyden, a Dutchman, was engaged in draining the fens and marshes in the Wash area, work which converted a large area of morass into valuable corn-growing land.

In 1616, Joas Croppenburg, another Dutchman, undertook to restore and keep in repair the river walls surrounding Canvey Island, about 3,800 acres in the Thames, and there were still extant two or three old Dutch houses to remind us of the occupation by the Dutch.

Again, in 1620, Sir Hugh Myddleton, in reclaiming Brading Harbour, in the Isle of Wight, called in Dutchmen to assist him in forming the embankment, etc.

Capt. R. T. Hinckes expressed diffidence in addressing the Society, as his experience in the subject of the paper had been gained as chairman of one of the most recently formed Drainage Boards, that of the River Lugg, constituted in 1920 ; but perhaps it was for that very reason that his remarks might be of value.

To Mr. Clayton, whose excellent paper he was glad to have had the opportunity of hearing, he owed whatever he knew of the subject.

The Lugg was a sinuous stream flowing into the Wye just below Hereford. For the first 14 miles it wended its way through a valley varying in width from about a mile and a half to a few hundred yards. About two miles below Leominster the valley widened out into a broad plain, and near this point the Lugg was joined by the Arrow.

Though the clearing of its natural and artificial obstructions had been discussed for many years, no practical steps were taken to effect improvement till after the Armistice in 1918. As part of the programme of the Food Production Department, local opinion had been canvassed in 1917, and some idea of the problems involved had been formed. Mr. Clayton visited Herefordshire in December of that year, and made a report to the Drainage Sub-Committee of the Agricultural Committee, a preliminary plan having been prepared by the County Surveyor, Mr. G. H. Jack, M.I.C.E.

Soon after the Armistice the Drainage Committee appointed Capt. Appleton, A.M.I.C.E., as their engineer, who set energetically to work preparing plans which formed the basis of the area included by the Ministry's staff, on whom fell the task of making the detailed survey. After the plans had been subjected to inspection for the period laid down by the Land Drainage Act, the Order constituting the Drainage Area was finally signed on March 30th, 1920. These brief details are given to show the large amount of preliminary work involved in setting up a Board. Once formed, the Board appointed its officials and let the first contract for clearing the lowest length of the stream in October, 1920. By June, 1921, assisted by favourable weather, 10 miles had been cleared. The programme of work being thereby completed, it was decided not to proceed further with the clearing of the main river, but as there was still some months before the first elected Board were due to come into office, plans were prepared for grading a subsidiary stream. It is worth recording that the rating for this latter work fell on the occupiers of the Lugg Common, who, at their annual meeting, approved unanimously the Board's proposals. The elections were held early in September, 1921, and evoked a good deal of interest, the necessary preparations entailing a great deal of work for the clerk. In the winter of 1921–22 the offer of an unemployment grant of 75 per cent. was taken advantage of to the fullest extent, some 20 miles of main river clearing and 14 miles of grading and clearing subsidiary streams being effected between November and June, over

£5,000 being spent on wages. Capt. Hinckes proceeded to give an analysis of the capital expenditure to date :—

	1st Programme.			2nd Programme.			
	10 Miles.			13 Miles.	Total.		
	£	s.	d.	£	£	s.	d.
Area "A"...	4,466	12	9	—	4,466	12	9
,, "B"...	3,829	13	6	738	4,567	13	6
,, "C" (part of)	—			250	250	0	0
	£8,296	6	3	£988	£9,284	6	3

For a total of 23 miles 404 yards.

This capital expenditure, assessed to Areas "A," "B" "C" in accordance with table in Lugg Order, works out at a capital expenditure per acre in Area "A" of £1 9s., in Area "B" 15s. 10d., and in Area "C" 5s. 6d. and 1s. 3d. respectively. The drainage work is, of course, still incomplete in Areas "B" and "C." With the repayment of this capital expenditure spread over 30 years and at the current price of money, the following rates per acre are necessitated :—

	s.	d.	
In Area "A" ...	3	5	diminishing annually.
,, "B" ...	2	1	
,, "C" ...	1	0	
In part of "C" ...	0	1½	

The average cost per mile for the work over the first 10 miles was £830 per mile, while the average for the next 13 miles was only £79 per mile. The marked drop in the price per mile is attributable to (1) the 75 per cent. grant, (2) falling prices and competition, with perhaps (3) somewhat lighter work necessitated in progressing up stream.

A sample of one of five other small Improvement Schemes carried out during last winter.

Little Lugg and Sutton Rhea, covering 16 miles 390 yards of stream and affecting 2,162 acres.

Total cost was £1,200 of which the Ministry of Agriculture found three quarters, leaving £300 to be spread over 15 years which necessitated a rate of 4½d. per acre for the first year. This rate will diminish annually.

The capital cost per acre works out at 2s. 9d. Out of the total of 2,162 acres, roughly 500 are in Area "B," and therefore subject to a rate for main river clearing of 2s. 1d. per acre.

It should be noted that the Board have full discretion as to the lands benefited, and therefore the area to be rated for each

" improvement." They decided by resolution to charge the work of clearing in the same proportion between the different areas or levels, as they are by their Order bound to charge works of " maintenance." Area " A " is the bottom area of about 1,500 acres, " B " the middle area of about 5,500 acres, and " C " the top area of 8,000 acres.

The land served by tributary streams amounting to 15,000 acres are only rateable for work carried out in their areas, and in addition for administrative expenses, which are charged as a flat rate over the entire area.

Though the work of main clearing does not involve the need of highly technical advice, the regrading and clearing of subsidiary streams calls for accurate levelling, and there are many engineering problems arising from time to time, especially as to the lands benefited by any improvement.

Three-quarters of the amount demanded for the first rate has now been collected, and confidence in the value of the work to the adjoining lands is now generally felt in the district. The work in the lower areas was commenced when wages were still high, and much timber and débris had to be cleared, Mr. Clayton describing the river as a " submerged forest."

In a period like the present, when the prices of produce and stock are often below the cost of production, farmers are naturally not inclined, as a whole, to shoulder additional charges on land, yet they appreciate the work of the Board as diminishing the inconvenience and loss arising from floods, many of the largest ratepayers being members of the Board, the total rate in one case amounting to over £70 per annum.

The Board were very fortunate in the appointment of their clerk, Mr. E. E. Diggory, whose thorough grasp of the many intricate legal problems continually cropping up, added to his intimate knowledge of the locality, has been of the greatest service.

Mr. H. R. Ward, asked by the President as to the incidence of drainage taxation in this country, and particularly with regard to the taxation of " high lands," said that the rule in England and Wales is that no lands can be taxed by a Drainage Authority except those which actually benefit from the existence or operations of the Drainage Authority. The taxation of the whole of each catchment area for the maintenance of the river system was recommended by a Select Committee of the House of Lords in 1877, but no action was taken on the recommendation. Since then the proposal to tax the high lands as well as the low lands has been before Parliament frequently, but has always either been rejected or " talked out."

Many competent judges believed that it was impossible to put the great rivers of England into proper order, or to maintain them, under the present system of taxation. As, however, the inhabitants of the high lands were more numerous than the inhabitants of the low lands in England and Wales, there did not appear to be any possibility of the basis of taxation being broadened as had been done in Holland.

With regard to Mr. Grantham's remarks on the rating schedule to the Ouse Drainage Act, Mr. Ward said that the figures quoted by Mr. Grantham had been prepared by the opponents of the Bill for the purpose of contesting the Bill in Parliament. The Ministry had also had figures prepared in support of the Bill by equally eminent witnesses, which differed widely from the figures quoted by Mr. Grantham. He maintained that the Parliamentary Committees acted properly and wisely in refusing to consider any of the figures. It was impossible to forecast what programme of work would be adopted by the Ouse Drainage Board or over how long a period their programme would be extended. This, of course, would make all the difference to the calculations.

With regard to the work done by prisoner-of-war labour, Mr. Ward suggested in two respects this work demonstrated a necessity of establishing Drainage Boards, viz., (a) by no other means could the recovery of the money spent be ensured, (b) the work done was both temporary and incomplete because of the absence of any authority with compulsory power to maintain the works and to extend them down to the outfall of each river.

With regard to the new Drainage Authorities referred to by Mr. Clayton, the Lugg Drainage Board had done conspicuously good work and had, indeed, made history. Their success was owing mainly, if not entirely, to the ability and energy of their chairman.

The recently established Clacton and Malden Drainage Board, which had only been in office for a few months, had already obtained a comprehensive report of the requirements of its district, and was well forward with a large programme of works.

The Ouse Drainage Board had been precluded, by the enormous size of its area, from undertaking within two years of its inception any of the capital works referred to by Mr. Clayton and Mr. Grantham. The Board had, however, been doing a great deal of useful and unostentatious work, and had already fully justified its existence.

Generally speaking, it might be said that the new Drainage Boards have shown both energy and ability in carrying out their duties and in dealing with the numerous legal and practical difficulties with which they are confronted.

Mr. Ward said that he desired particularly to take this and every other opportunity which might offer itself of explaining that the Ministry's policy was not to rush new Drainage Authorities into expenditure which their districts cannot reasonably afford. In every Order constituting a new district the Ministry had to nominate the members of the first Board. The Ministry thus establishes in each case a Board which it believed could be trusted, and then proceeded to trust the new Board accordingly. The Ministry fully appreciated the fact that in many districts times had been and were still so bad that works which were urgently needed had to be deferred. At the same time, experience had shewn the utility of having in existence a Drainage Authority which could take immediate advantage of any opportunity which might occur of doing work cheaply, for example, by means of the Government Grants for the relief of unemployment.

Mr. A. Havelock Case, M.Inst., C.E., said the question of land drainage and in particular its economics was of more importance to the country than many people realised. There was much truth in the old saying that use is second nature, and it was, always difficult to persuade persons to make progressive steps more especially when such steps necessitate immediate expenditure with only prospective or future benefit.

He had found when discussing the question with agricultural friends that a ready admission of the benefit was shown, and there was a desire for improvement work on the drainage channels, ditches, brooks, rivers, etc, so long as the work was to be done at some other one's cost, but as soon as the fatal word " rates " was mentioned then a preference was shown for existing evils rather than a flight to those they knew not of. For these reasons the figures of cost given by the author were extremely interesting and valuable, and they should be of great help to those authorities who had to meet difficulties from this cause. The author appears to have been more fortunate than the speaker as regards economy with German prisoner labour. It was his duty to supervise the clearing of about 22½ miles of fenland waterways by this means during the war, and he found the work more costly than if it had been done by free labour. He had to meet the marked dissatisfaction, and with just cause, of those riparian owners and occupiers who were called upon to pay for the work. He attributed the cause as due to military and other unavoidable restrictions necessary to discipline.

The watershed of these particular fens was about 45 square miles, but an area of only 4¾ square miles was rated for general purposes, whilst the cost of cleaning out and maintaining the waterway was met by the owners of property abutting on the waterway. The average width of waterway dealt with was about 10 ft. and depth 3 ft. The main channels were nearly 30 ft. wide, of course, much wider than the subsidiaries, which were, in many cases, merely ditches. The cost worked out at an average of about 24s. per chain in the proportion of two-thirds paid to the State for the use of the German prisoners, and one-third the cost of tools, boots and free-labour supervision, all engineering work and supervision being given gratis.

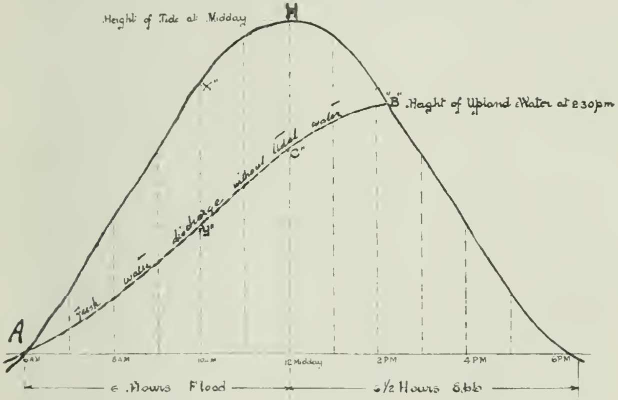
The speaker had had to deal with a recent instance where it had been proposed to set up a statutory authority for the purpose of clearing and maintaining waterways recognised as being neglected and under no control. The principle adopted was the recognised one of " no benefit no charge," or, as this was interpreted, only lands directly affected by floods were to be saddled with the cost of improvements. This meant that the burden of providing funds was placed upon such a narrow strip of land on the two sides of the waterway as to produce at any reasonable rate much too small an income to be of any practical use. The proposal was consequently turned down.

For the purpose, in his opinion, of excusing inaction it was sometimes argued that flooding was good for meadow lands, but surely all such benefit would be better achieved by regulated irrigation than by uncontrolled drowning. In a word it was the economics of the question that would settle it. We ought, therefore, to welcome Mr. Clayton's able and lucid explanations of the way in which these difficulties might be partially met. It was certain that many interested landowners or occupiers did not realise that only concurrently with the progress of the work had funds to be provided with the result that costs were spread over a corresponding length of time with the economic advantage so clearly set out by the author by a concrete example in tabular form.

The author was good enough to refer kindly to the speaker's work in connection with the River Ouse, where the much-debated question whether the effective discharge of a tidal river was improved or not by the exclusion of the tide by means of a dam with sluices at its mouth, was argued at a lengthy enquiry held at King's Lynn. He then held and still did the opinion that nothing but evil would result from shutting out the tide. This, of course, was a principle subject to modification if necessary to meet special conditions. He contended that practically the same volume of water would be discharged to the sea during a given tidal cycle, whether the tidal water were freely admitted or whether it were totally excluded by being held up at the river mouth. The arresting effect of the rising tide cannot be avoided by such means ; the effect was much the same in either case. If the upland waters were in excess of the incoming tidal waters it was obvious that a dam was useless. The same, but in a less degree, applied when the two volumes of water were equal. It was only when the issuing river water was smaller than that of the rising tide that the question could arise, and then the only effect of the incoming tidal water was to supply the necessary extra volume of water required to fill the river to the added height of the tide with the added advantage of the increased scouring effect of the increased volume of water. The natural effect of excluding the tide and diminishing the volume of water passing to and fro in the channel would be to cause the channel to adjust itself to the smaller volume of water it had to carry by gradually silting up.

He therefore strongly endorsed the author's expressions of opinion as to the necessity of maintaining and improving tidal outfall channels.

The following diagram illustrates the point :—



The horizontal base line represents a tidal cycle of say 6 hours flood and 6½ hours ebb—6 a.m. to 6.30 p.m. The ordinates represent the rise and fall of the tide in front of the dam and of the impounded waters of the river behind the dam.

In the absence of a dam, that was to say with the channel freely open to the incoming tide, the two sources of supply coming from the two opposing directions would commingle and flow together in the relative proportion of their respective volumes and the rise and fall of the combined waters would be represented by the black full line curve. Let the channel be closed by a dam or sluice to the admission of tidal water from the moment that the rising flood tide was level with the issuing fresh water until the falling ebb tide was also level with the accumulated fresh water held up by the dam. In the meantime all discharge from the river must have ceased. The relative volume of upland waters to tidal waters must be either more than, equal to, or less than. If "more than," the result would be that the excess river water would tend to push open the sluice or to sweep away the obstacle. If the two volumes were equal, the effect would be nil. If the incoming tide were in excess of the downward flow of the upland waters, the discharge of the river would be arrested, and it would pond up and accumulate behind the dam. This was the only one of the three possibilities which need be considered. In such a case, instead of the full black line curve representing the combined waters, it would represent only the tidal waters against the dam, and the smaller volume of fresh water coming down the river would be represented by the dotted black line curve. That was to say, that soon after low water, say 6 o'clock a.m., the incoming tide would meet and be level with the outgoing stream of fresh water at A. The tide would rise at a greater rate on the one side of the dam or sluice than the fresh water would on the other. So that at high water, mid-day, the arrested and accumulated fresh water which had been ponding itself up behind the dam would only be at the point C several feet below that of the high tide at H, and would consequently still be rising whilst the tide was falling. Suppose that the rising pond of river water levelled up with that of the falling tidal waters at 2.30 p.m., the dam would then be removed or the sluices opened, and the imprisoned water released to mingle with the falling tide until low water turns again, say, at 6.30 p.m. It should be noted that in the absence of a dam, the river would be discharging its mingled waters from the point of time H on the diagram, whereas with the dam no discharge could take place until the point B was reached. A loss of time and a loss of head. In such a case the volume of tidal water coming into and passing out of the channel below the dam would be represented by the area A H 12, whilst the volume of stored and discharged upland waters would be represented by the area A C B 2. The area of difference, A H B C A, represents the loss of the excess tidal waters which had been shut out from the river and the loss of which for scouring purposes was an evil. In the case of a dam or no dam the same volume of fresh water was passed. Take the hour of 10 o'clock with the open river, the surface would be at the level X, and made up of fresh and tide water in the proportions 10 y and Y X ; with the dam the fresh water would be at 10 y and the tide water 10 x. There was no increased discharge, but a loss for scouring purposes of the volume-X y above the dam.

Practice supported theory by the fact that the system was adopted on the Nene at Wisbech with such disastrous results that the dam and sluice were removed and the river restored to its free and open and natural condition.

Author's Reply.

Mr. C. H. J. Clayton, in replying upon the discussion, said that he could not express too much appreciation for the kindness of those who had contributed to it. He had rather anticipated that there might be a certain amount of criticism, but he had to acknowledge with gratitude that he had been let off very lightly. The Chairman had truly remarked that expenditure upon land drainage works was promptly remunerative, and that in that respect it differed somewhat from other kinds of engineering where dividends might be long in arrival.

Capt. Hinckes had been able to show from his recent experience in the Lugg valley that very valuable works could be carried out at moderate cost, and that the incidental acreage rates were insignificant when compared with the increased productivity of the affected lands.

It was interesting to learn from Mr. Korthals-Altes that British farmers were not alone in their conservative opposition to expenditure on drainage works, but his experience in Gelderland was encouraging as tending to show that Dutch farmers at any rate could be converted to sounder economic opinions if approached in the right way. The author was of opinion that many British farmers and owners who may have been more or less indifferent in the past were now coming to recognise, especially in these lean times for agriculture, that efficient drainage was a paying proposition. It was true that there were many valuable areas of agricultural land spoilt by mining subsidencies. No doubt many of them could be restored to productive conditions, but probably only by the installation of pumping plant.

As to rating areas, it would not be proper for him as a Government official to offer any opinion as to the wisdom of Parliament in excluding uplands from rating incidence, but he recognised that it was still a debatable subject.

He was frankly a little surprised that Mr. Grantham should have quoted figures prepared by Mr. Keen, a very eminent actuary, doubtless, but one who was retained by the opponents of the Ouse Order. Mr. Grantham admitted that his own estimates and the author's estimates were substantially the same, but apparently preferred to scrap those figures in favour of a sum which was pretty obviously intended to frighten Parliament into rejecting the Order. Mr. Case, who certainly had a very intimate acquaintance with conditions in the Ouse valley, and had prepared careful estimates of cost, did not appear to share Mr. Grantham's pessimism, and the author was happy to note that Mr. Case preferred an adherence to the figures which the author had quoted as based upon those of Messrs. Grantham and Case.

Although it was perhaps only an incident of the paper that the desirability of a free tideway was mentioned, Mr. Case's contribution to this subject was of immense value. Cross tidal sluices for reservoir purposes had their advocates, no doubt, but after having heard all the arguments *pro* and *con* the author was as firmly convinced as was Mr. Case that they could not be expected to produce anything but evil. Mr. Case's diagram and description should demonstrate that, at least, discharges would not be increased or accelerated, even if dangerous siltation above and below the dam did not take place.

The author was grateful to Mr. Ward for his advocacy of the policy of establishing Drainage Boards and for his reference to the instances of the new authorities which were demonstrating the wisdom of co-ordinated effort to improve conditions in their areas.

Mr. Collingwood's enquiry as to the enclosure of tidal lands in this country did not warrant a very encouraging reply. The Ministry of Agriculture had, two years ago, essayed reclamation work in the Wash area as a means of alleviating unemployment, but the cost of the works proved to be out of all proportion to the value of the area gained, and the experiment was not repeated. The same money spent on drainage works would probably have proved very much more remunerative.

Major Martin was very generous in his reference to the work of the Ministry of Agriculture and to the author's contribution to that work. It was very gratifying to receive such a tribute from an old colleague who understood some of the difficulties.

In conclusion, the author thanked members and visitors for their kindly reception of his paper, and expressed the hope that its subject—perhaps not a popular and attractive one—might receive from landowners and agriculturists generally a larger measure of attention than they had been wont to devote to it. He was firmly convinced that hundreds of thousands of acres of good land in this country now derelict could be redeemed for agriculture as a result of well-considered drainage works, and that in most instances very handsome returns on capital expenditure could be shown.

Monday, November 6, 1922.

T. J. GUERITTE, B.Sc. (Paris), M.Soc.Ing.Civ. (France), F.S.E.,
PRESIDENT, IN THE CHAIR.

THE ATLANTIC CRUISE OF H.M. AIRSHIP R. 34

By E. E. TURNER, A.M.S.E.

(A Chief Engineer of the Airship on the Trip.)

OBJECT OF CRUISE.

The voyage was not carried out as an adventurous trip, but had many definite objectives. In the first place, to gather meteorological data for future reference, and the choosing of what may be termed "trade winds" and altitudes for further journeys. It may be here mentioned that valuable data were collected in this respect. Then, to show the commercial value of airships, namely, the carrying of valuable light cargo, or special sample merchandise, which would reach its destination more quickly. The journey in a ship built for commercial work being completed in less than half of the time taken by liners, business competition would become keener owing to the time saved in the crossing, working to schedule being an easy matter.

To one who has crossed the Atlantic many times, the cold, damp fog nuisance in the Canadian and American waters is most annoying. After probably having a bad Atlantic swell, and the ensuing sea sickness during the crossing, one feels that the sooner they are off the boat the better. With the airship there is no sea sickness, or, as many imagine, air sickness. No sensation is experienced, only that of comfort and the desire for more. The ship flies over fog which is, at its worst, not more than one thousand feet high, and as the strength of the sun increases, or on the advent of a slight wind, the fog disappears making the atmosphere clear for a landing. Even rain and storms are generally circumvented, as the pilot will fly higher to miss rain and the meteorological reports are received as required by wireless.

CONSTRUCTION OF SHIP.

The R. 34 was built and equipped by Wm. Beardmore & Co., Ltd., of Parkhead and Dalmuir, at their Airship Works at Inchinnan in Scotland.

Length	647 ft.
Maximum Diameter	78 ft.
Total Weight, empty	32 tons
,, ,, loaded	60 tons
Gas capacity ...	2,000,000 cub. ft.

The use of duralumin in the construction of the hull, cars, etc., makes an account of the properties of this material desirable, especially with reference to its working qualities as developed by experience.

Composition, Specific Gravities and Melting Point.—Duralumin is made in various compositions and has, with the exception of small quantities of impurities, the following composition :—

Aluminium ...	...	95·5 to 93·2 per cent.
Magnesium	...	0·5 ,, ,,
Copper ...	...	3·5 to 5·5 ,, ,,
Manganese ...	...	0·5 to 0·8 ,, ,,

Lead, tin and zinc which have an unfavourable influence upon the permanence of aluminium alloys, are not found in duralumin.

The specific gravity varies, according to composition and hardness, from 2·75 to 2·84. The melting point is 650° C.

WORKING OF DURALUMIN.

Like other metals duralumin can be rolled into plates and shapes, and behaves in a similar manner, in that the elongation decreases as hardness increases. Tube blanks, however, can be made only by pressing and not by the oblique rolling method. duralumin can be worked well at a temperature of 400° C.

Tempering.—Duralumin can be tempered like steel, by heating and sudden cooling. For this purpose, plates, tubes and shapes are heated to between 480° C. and 510° C. and quenched, then aged, that is, the treated material is simply set aside. The original strength characteristics are very nearly restored after the quenching, but the tensile strength continues to grow with the time of ageing. The elongation does not decrease, but remains at least the same, and usually increases slightly. During the ageing, work cannot be done on it which would change the section, as, in that case, strength will not increase any more.

HULL STRUCTURE.

The hull was constructed of duralumin, every part being varnished to prevent atmospheric corrosion. The cross section takes the form of a polygon with thirteen straight sides, and built up of main transverse frames rigidly wired. These frames are placed every ten metres apart, with intermediate transverse frames of lighter construction placed between, prevented from radial distortion by wires connecting the ends of each straight girder to the centre. The wires are known as " radial wires."

The transverse frames are connected by straight girders, known as the main longitudinal girders, and placed at the thirteen angles in the main transverse girders. Intermediate longitudinals are also fitted, giving a final appearance of a polygon with twenty-five sides. The main longitudinal girders are cross-wired from their ends to the main transverse, and the intermediate longitudinals are again wired to the intermediate transverse, these wires being termed major and minor diagonals respectively. At the bow and stern the transverse frames are reduced in diameter, giving the required shape.

A triangular keel is built inside the hull as part of the structure, the keel acting as the load carrier between main and transverse frames. This keel is carried the whole length of the ship and has a small walking way about a foot wide, except at the crew space where it is boarded with 3-ply wood across the base of the triangle forming the keel.

Along the keel and so disposed as to distribute the load at its correct proportion, the fuel and water tanks are carried. The fifty petrol tanks are cylindrical in shape and are arranged on each side of the walking way. They are built of aluminium, each tank holding a little more than ninety gallons. Some of these tanks are permanently fixed, but the majority are slip tanks, each having a releasing gear. These are slipped only in case of emergency should the ship become abnormally heavy, and after all water ballast has been disposed of. The fixed tanks are arranged over or about their respective cars. All petrol pipe lines are arranged on only one side of the walking way; the control and gas valve wires being arranged on the other side. Oil service tanks are arranged directly over each car and can be heated by hot water circulation if necessary. All fuel is gravity fed.

ENGINES AND MACHINERY.

The engines and machinery which gave such a wonderful demonstration of their power and reliability under all conditions, were built by The Sunbeam Motor Car Co., Ltd., Wolverhampton.

The Sunbeam-Coatalen "Maori IV." engines which were fitted are a development of the type supplied by the makers for use on seaplanes during the war, but, owing to the different conditions under which they have to run on airships, the deviation from the original design is so great that they may be regarded as a distinct type. One of the features affecting design was the fact that in an airship it is easily possible to make adjustments, and even small repairs during the course of flight, which cannot be done on a seaplane. Again, the presence of a clutch enabling the engine to run completely disconnected from the propeller, necessitates the provision of a controlling device which takes the form of a centrifugal governor. Fuel economy is of the utmost importance in an airship engine, which is called upon to run for long periods, the sum of a small fraction of a pound in the consumption per brake horse-power-hour, more than compensating for a considerable increase in the weight of the engine. Further,

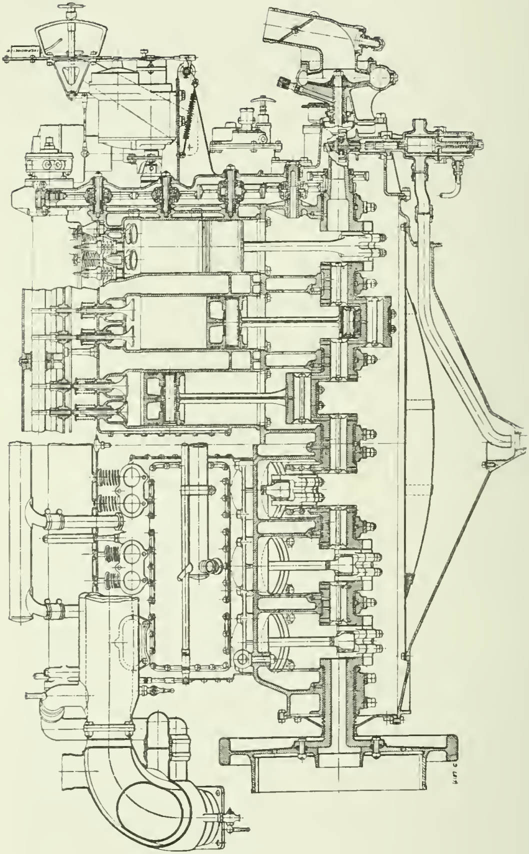


Fig. 1.—Longitudinal Section through Crankshaft and Cylinders.

the engine must run economically for long periods at any speeds, from the maximum to the minimum, and consequently special provision had to be made to ensure the maintenance of the correct temperature of the oil and cooling water, since the speed of the air past the radiators is not proportional to the power output of any particular engine, as it is in the case of the aeroplane or seaplane. In the aft engine car, which carries the two engines or the twin engine unit, the radiators can be raised or lowered above or inside the engine car. The radiator is lifted by wires and pulleys in parallel slides, and located by a safety device in the required position. Extra long armoured flexible hose is fitted to allow for the extended position. In the forward and wing cars the whole radiator is fixed in position outside the car and a metal ventilator of the folding shutter type is fitted.

After these preliminary remarks we may proceed to describe the engines in detail with the aid of drawings and photographs. The left-hand portion of Fig. 1 is a longitudinal vertical section on the centre line of the engine, while the right-hand portion is the section through a group of cylinders which are inclined at thirty degrees to the vertical, as shown in the transverse section, Fig. 2. There are five engines, all exactly similar, each engine giving 270 brake horse-power at 2,100 r.p.m., so that the total power amounts to 1,350 brake horse-power.

The engines are of the twelve-cylinder type, two rows of six cylinders each, being arranged in the form of a " V " with an angle of sixty degrees between them. The bore of the cylinders is 100mm. (3·94 in.), and the average stroke 138·5mm. (5·45 in.). The cylinders are of cast iron in blocks of three, but the water jacket is formed, to a large extent, of aluminium plates screwed on to the main casting. This construction gives a useful reduction in the total weight, enables the cores to be firmly supported during casting, and also provides a convenient means of access to the interior of the jacket for cleaning purposes. The cylinder blocks are bolted to the crank-case, which is an aluminium casting, as shown in Figs. 1 and 2. The joint flange of the crank-case is well below the centre line of the crank-shaft. In addition to stiffening the crank-case this design enables the bearing caps to be accurately fitted between two cheeks, and thus relieves the bearing bolts of all sheer. Two exhaust valves and two inlet valves are fitted in the head of each cylinder, all the inlet valves and all the exhaust valves for each row of cylinders being arranged in two separate lines parallel with the crankshaft. An inspection of Fig. 2 will show that this method of operating the valves differs from that more usually employed, a separate overhead cam-shaft being used for each line of valves, instead of the more common arrangement of a single camshaft operating two lines of valves through the medium of tappet levers. The former arrangement has the advantage that the entire cam-gear can be easily and quickly removed, and it also enables one of the sparking plugs to be placed in the centre of the cylinder head, thus ensuring high ignition efficiency. The positions of the two plugs, with which each cylinder is provided, is shown on the right of Fig. 1. Each pair of valves is operated directly by a single cam, side thrust on the valve stems or tappets being avoided by the provision of fingers interposed between the cams and the ends of the tappets, as shown in Fig. 2. The tappets are made in two parts, and are extensible for adjustment and for taking up wear. The valves are of tulip form, and are fitted with double helical springs, the washers for which are secured to the valve stems by means of split conical washers.

The pistons are of a special hard aluminium alloy, well ribbed and are each provided with a central stem extending downwards from the crown, and bedding on to the centre of the gudgeon pin. This arrangement serves to support the crown of the piston, and also assists in equalising the temperature. The gudgeon pin itself is secured by means of two wire spring rings, which enter half way in the pin bosses, and the pin is prevented from rotating by the usual feather. The pistons, which are comparatively short, are fitted with three gas rings, and one scraper ring.

The arrangement of the articulated connecting rods is most clearly shown in Fig. 2. The rods are machined from nickel-chrome steel forgings. The leading or main rods, *i.e.*, the one on the left of Fig. 2, is of the usual form, and is directly connected to the crank-pin, while the trailing, or link-rod, on the right of the illustration, is connected to a pin held in a fork formed on the main rod. This fork is shown under the third cylinder from the fly-wheel end in Fig. 1. This arrangement has a considerable advantage over that more usually adopted in the case of two connecting rods, working on the same crank-pin, in that one of the rods may be replaced without having to bed a second rod on to the back of it. In extreme cases, with the usual arrangement, it may be necessary to replace one damaged rod by two new ones, both of which would have to be bedded. The effect of the construction, illustrated in Fig. 2, is that the length of the stroke of the piston connected to the link rod depends upon the angle between the axis of the main rod and the ears of the fork to which the link rod is connected. The angle chosen by the makers for this detail is such as to give a slightly longer stroke to the link rod piston, but, at the same time, it allows both centres of the link rod and the crank-pin centre to be in line at the correct angle of rotation, *i.e.*, when the piston connected to the main rod is at the extreme top end of its stroke. There would also be considerable alteration in the effect of the secondary out-of-balance forces, and additional reversing stress would be

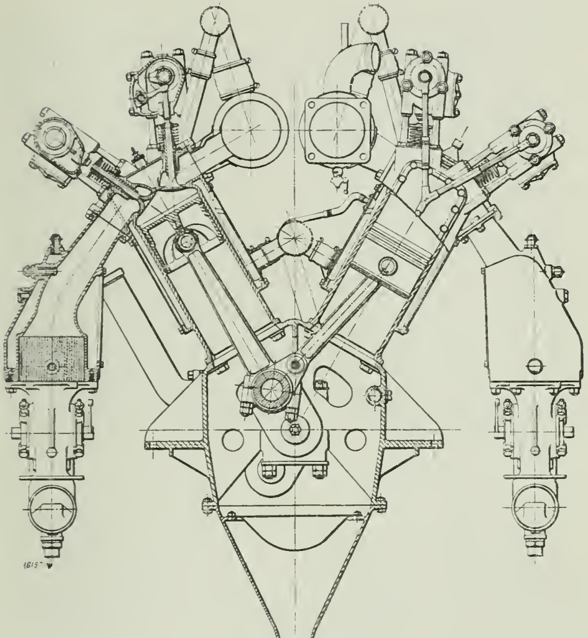


FIG. 2.—TRANSVERSE SECTION THROUGH CYLINDERS AND INLET PIPE.

introduced on the main rod, which would be detrimental both from the point of view of fatigue and of silence in running.

The crank-shaft is a stamping of nickel-chrome steel, forged in such a manner that the fibres of the material are continuous throughout the whole of its length. The shaft is supported in seven large bearings, lined with white metal, and large lightening holes are bored through the journals and crank-pins, as shown in Fig. 1. The ends of the holes are closed by light steel washers held in position by bolts so as to retain the oil which is transmitted through the shaft from the main journals to the crank-pins and connecting rods. Lubrication of the link-rod pin is supplied from the same source through ducts connecting the main big-end bearings with the hollow pin and bronze bush with which the link-rod is fitted.

The camshafts are housed in casings of cast aluminium which are self-aligning and give a support sufficiently flexible to take up any movement between the adjacent groups of cylinders, which might otherwise interfere with the bearing of the shaft. The camshafts themselves are machined from solid forged bars, and are made hollow, oil being supplied through the central hole to lubricate the cams, small holes being drilled through the backs of the cams for this purpose. The camshaft bearings, of which there are seven for each shaft, are also lubricated from the centres of the shaft. The camshafts are driven by spur wheel trains, one of which is shown in Fig. 1. All the wheels are of air hardened nickel-chrome steel and run on ball-bearings. Various auxiliaries, including the magnetos, revolution counter, air pumps, etc., are driven from the gear train by easily detachable couplings. The wheel covers, which are distinct from the cylinder castings, can be removed separately, and the auxiliaries can also be removed without interfering with the timing wheels or any other parts of the engine. The housing of the camshaft drive wheels also houses the governor gear, which is arranged to cut off the ignition when the speed of the engine reaches 2,500 r.p.m., or when the oil pressure falls below 25 lb. per square inch. Details of the governor gear are illustrated in Figs. 3 to 6, and its position is shown on the right of Fig. 1 just below the magneto. The governor is of the centrifugal type ; its action being controlled by a spring shown in Fig. 3, which is adjusted and sealed at the makers' works. Movement of the governor arm rocks a horizontal tubular shaft through the medium of a short forked lever, and this shaft operates a cut out in the ignition system.

The device for protecting the engine against failure of the oil pressure is shown in Fig. 5, and consists of a small cylinder containing a piston, the left-hand side of which is acted upon by oil pressure. Under normal working conditions the piston is held outwards against the action of the spring shown in the upper part of the figure, the trigger which passes through an opening in the cylinder wall then being in contact with the periphery of the piston. A failure of the oil pressure will allow the piston to be drawn back by the spring so that the trigger moves into the position shown in the illustration. In this position the lower spring tends to turn the tubular shaft in the opposite direction to the main governor spring, partially neutralising the latter, and thus allowing the governor to act at a much lower speed than the normal, viz., 300 r.p.m., a split sleeve on the shaft shown in Fig. 6 prevents the pressure of the lower spring from coming on to the shaft in normal working, and, in starting up, is held back by a hand plunger, which is released when the engine is running.

The engine is started by gearing, operated either by hand or by electric motor, and situated in the front cover immediately under the governor. It is of the ordinary design, except that, instead of the usual ratchet for over-running, the "throw-out" on starting is obtained by a gear-wheel with spiral teeth incorporated in the mechanism. Compressed air starters, similar

FIG. 3.

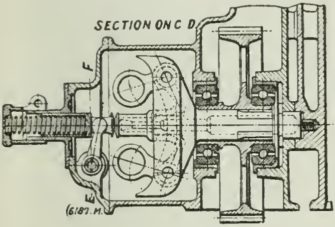
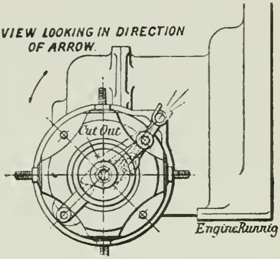


FIG. 4.



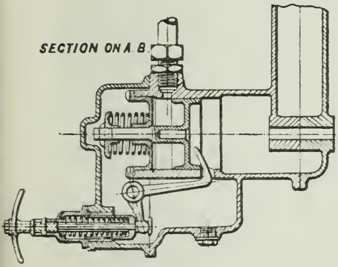


FIG. 5.

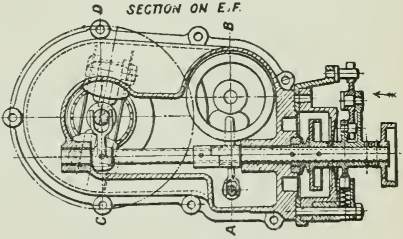


FIG. 6.

to those employed in Sunbeam engines, were fitted when the engines were originally installed, but these were found to be unnecessary, and were subsequently removed.

In connection with the lubrication system of the engine, four pumps are provided, all of which are of the gear wheel type, and are driven from the crank-shaft by skew gearing. Of these, the main suction pump, shown in section at the right-hand bottom corner of Fig. 1, draws the used oil from the crank-case and returns it to the tank, while an auxiliary suction pump is used to collect the oil from the cam sleeves and other parts in which it would otherwise accumulate. The main pressure pump draws oil from the tank and supplies it at a pressure of 45 lb. per square inch to the crank-shaft for lubricating the main bearings and the big ends of the connecting rods. An auxiliary pressure pump is used to supply oil at a lower pressure to the cam-shafts, etc. The filtering of the oil is a matter of considerable importance in an engine which is required to run for long periods without stopping. In the engine being described, filters are provided on both the pressure and the suction sides of the main pressure pump, and the filters are duplicated so that one half of either can be taken out for cleaning, while the other half is in use. The quantity of oil circulated is very large and the circulation system includes an oil cooler fixed on the outside of the car, in order to dissipate the heat generated ; the oil connections being arranged so that the coolers can be cut off more or less in order to regulate the temperature, and the oil supply can be replenished while the engine is working through pipes connected with the main tank in the hull.

Four carburettors of the Claudel-Hobson B.Z. type are fitted to each engine, each carburettor supplying a group of three cylinders. The carburettors are fitted with a device to compensate for the changes in density of the air at different altitudes. The inlet pipes are provided with hot water jackets and, to guard against the possibility of fire in the cars, they are fitted with flame-resisting baffles placed immediately over the carburettors, as shewn in Fig. 2. The baffles consist of grids formed of aluminium plates and their effect is to lower the temperature of any ignited gases in the inlet pipe sufficiently to prevent the passage of flame to the carburettor. On the suction side of the carburettor, the intakes are provided with gauze covered mouthpieces and the petrol drains are taken outside the car.

The exhaust arrangements are clearly shown in Figs. 1 and 2, from which it will be seen that they comprise two water-cooled manifolds placed between the cylinders, one being connected to each row. At the after end of the engine the manifolds are connected by a water-jacketed breeches pipe to a transverse pipe section, which leads the gasses to the external exhaust pipe outside the car. The whole of the cooling water for the engine is circulated by a large pump of the centrifugal type, driven directly from the engine crank-shaft and shown in section in Fig. 1. The control valves in the pipes are provided for use when the ship is in the shed, connection being made to an electric heater, which keeps hot water in circulation, and thus avoids the necessity for draining the jackets in cold weather. The levers for regulating the ignition, and the throttle, and the atmospheric controls, are grouped together on a small instrument board mounted on the forward end of each engine, as is shown in the interior view of the aft engine car. With this arrangement, the fewest possible number of connections have to be made or broken when replacing or removing an engine. Each engine is fitted with a fly-wheel of sufficient weight to enable the engine to run when disconnected from the propeller. The fly-wheel and the driving ring, which is recessed to take the blocks of resilient material for transmitting the drive to the gearing will be noticed.

The total petrol consumption of the five engines is 71·5 gallons per hour with full load near the ground, the consumption falling to 59·5 gallons per hour at 5,000 feet. At cruising load the consumption near the ground is 47 gallons per hour, while at 5,000 feet the corresponding consumption is 39·5 gallons per hour. In Fig. 7 results of a bench test of one of the engines are given; and from this diagram it will be seen that the petrol consumption ranges from about 0·48 pint per b.h.p. hour, when the engine is running at 1,600 r.p.m., and giving 200 b.h.p., to about 0·52 pint b.h.p. hour at full speed, when the output is about 275 b.h.p.

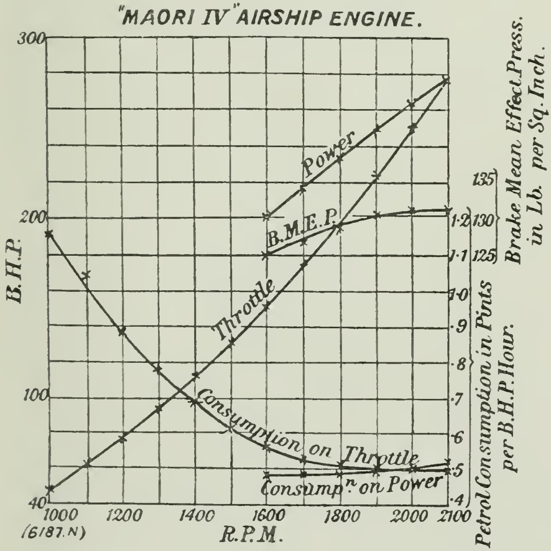


FIG. 7.

The brake mean effective pressure is also given for this range of speeds, and the consumption on the throttle is given for all speeds from 1,000 r.p.m. to 2,100 r.p.m. To obtain the throttle curve, it may be explained the engine was opened out to full power, and sufficient load applied to give the maximum speed of 2,100 r.p.m. The load was maintained and the throttle gradually closed, giving the results shown in the diagram, the curve marked " consumption-on-throttle " giving the petrol consumption during the operation. The power curve was obtained with the throttle fully open during the whole of the test, the load on the brake being gradually increased so as to reduce the speed as shown.

MACHINERY.

Before describing the machinery in detail it will perhaps be advisable to refer to the general arrangement of the propelling machinery. There are in all five cars or gondolas supported from the main structure of the ship. Of these the foremost two are situated in the centre line of the ship, one immediately behind the other, so as virtually to form a single car. Of these two cars the forward one is used exclusively for navigation purposes, while the after one contains a single engine, driving a " pusher " air screw through a permanent reduction gear. In a position rather forward of amidships two wing cars are suspended, one on each side of the centre line, at a slightly higher level than the forward car. There are also engine units driving pusher screws through a reduction gear, but a reversing gear is incorporated with the reduction gear in these cars, so that the air screws can be reversed for manœuvring purposes. The remaining car is situated on the centre line of the ship towards the after end, and contains two engines, both driving a single air screw.

Fig. 10 is an interior view of the after car looking towards the propeller, and showing the after portion of the car only. The large pipe shown in Fig. 10 is an air inlet trunk for ventilation purposes. Generally speaking, the lay-out of the machinery in each car is similar ; but for the purpose of description reference will be made to the arrangement of the wing cars, attention being called to any variations in detail when necessary.

A longitudinal section of the port wing car is given in Figs. 9, while Fig. 11 is a reproduction of the interior of the starboard car. In all cases the engine is coupled to the reduction gear through a fly-wheel, multiple disc clutch, and an intermediate shaft with a universal coupling of tooth type, which is fitted to allow for any distortion which may take place in the car framework. Flexibility of the support of the transmission units was one of the chief problems to be overcome in designing the installations, but the tooth type " couplings and the girder

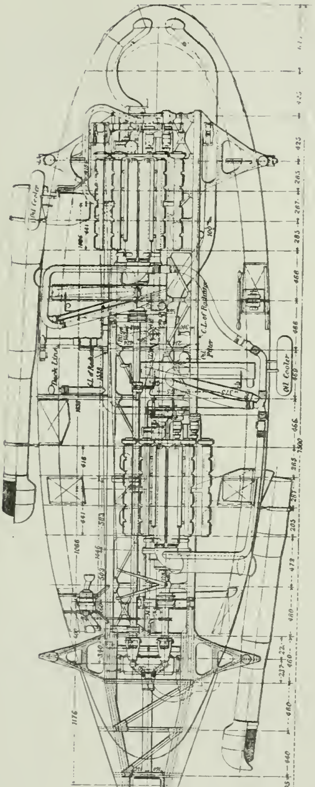

Oil Cooler
Oil Cooler
C.L. of Radiator
Oil Filter
Tank Line

Fig. 8.

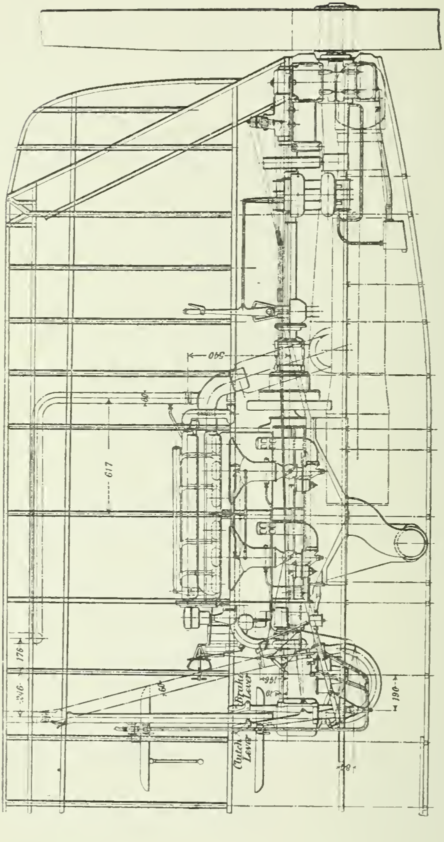


FIG. 9.

supports for the intermediate shaft have obviated any trouble from this cause.

The flywheel on the engine crankshaft drives the transmission by means of blocks of resilient material fitted into recesses machined in the inner surface of a driving ring formed on the face of the flywheel, the blocks being faced with hard brass held in position by small wire clips. Close to the flywheel and distinguishable in Figs. 8 and 9, is a clutch of the corrugated multiple-disc type, composed of an equal number of bronze and steel plates arranged alternately. Fig. 9 shows the method of operating the clutch from a vertical lever placed forward of the engine and connected to a horizontal lever on the clutch by means of a wire cable taken round two pulleys. A central spring is fitted and is operated by eccentric links and pins through two ball thrusts, this arrangement serving to balance the spring thrusts when running, and also largely to diminish the end thrust on the whole gear when declutching.

The clutch shaft is separately supported on double rows of ball bearings with spherical races, so as to give flexibility. The clutch is connected to the gear box by means of a short intermediate shaft with the tooth-type couplings at each end. The teeth are lozenge-shape so as to give greater flexibility. The gear case is constructed of well-webbed aluminium castings, and the method of fitting it in the wing cars is shown in Fig. 9. The propeller shaft and the gears give a speed reduction ratio of 1 : 3.86. The flange to which the propeller is bolted is forged solid with the shaft, and the loose outer flange is keyed on to the end of the shaft in the usual manner. The shaft is supported on two roller bearings, one on each side of the gear wheel, which is fitted immediately behind the propeller, and the inner bearings are also of the roller type. The thrust of the propeller is taken by a thrust race formed by two spherical-shaped washers, and one row of balls, the clearance being arranged so that this single row takes the thrust in either direction.

The reversing mechanism is of the usual sliding sleeve pattern, the countershaft, which is arranged on the port side of the gearbox, carrying the main sliding sleeve, which is formed of two wheels. Only the two main reduction wheels are in engagement in forward driving, the sleeve on the driving shaft then having its clutch engaged with the pinion shaft. A brake is mounted on the driving shaft, and by this means the rotation of the propeller may be stopped when declutching. Reversing is effected by the manipulation of two levers, one connected to each of the two sleeves. The arrangement is perhaps more liable to misuse than the more common form of gate change used in motor car practice, but among other points in its favour is the decided advantage that only two gear wheels are in mesh when running in the normal

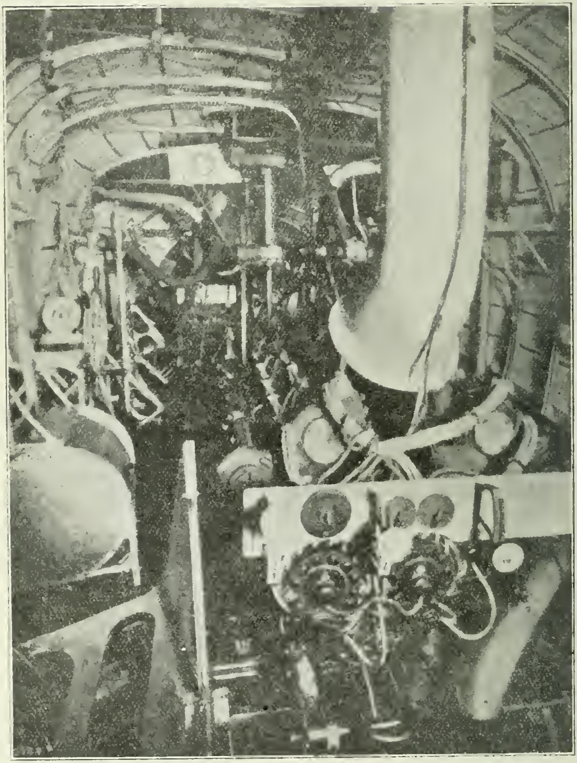


FIG. 10.—INTERIOR VIEW OF AFTER CAR, LOOKING AFT, R. 33.

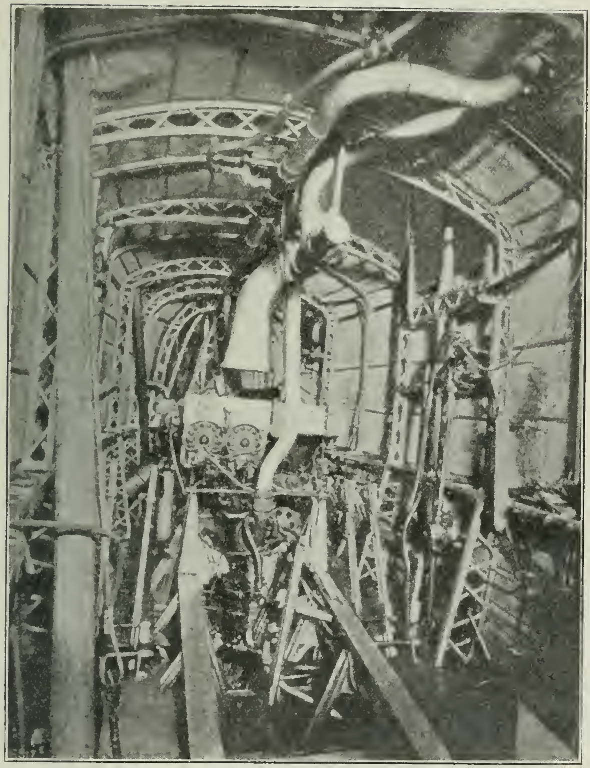


Fig. 11.—Starboard Wing Car, Looking Aft, R. 33.

direction. Reversing is, of course, only necessary when landing or manœuvring for a landing, so that the gear is only in use for a very small percentage of the total running.

The construction of the reduction gear for the forward car is similar to that described, except that in this case no reversing gear is fitted. Lubrication in both cases is effected by means of an oil pump which directs a stream of oil between the teeth at point of contact. An auxiliary tank is provided so that a large quantity of oil is circulated, and any heat generated is readily dissipated. Large vent pipes are also fitted to the gear-boxes, and these induce a flow of air through the boxes when the airship is under way, thus effectively cooling them.

In the case of the after car both engines are fitted with clutches similar to those previously described. The power from the forward engine is transmitted through a long intermediate shaft passing just clear of the bearers of the after engines. This shaft and the short shaft from the after engine are both fitted with tooth couplings. The shafts run in double ball bearings mounted on transverse bearers, and similar bearings are also housed inside the end of the pinion shaft of the gear-box. Close to the gear-box, sliding dog-clutches are fitted so that either, or both, of the engines can be completely disconnected from the propeller at will. In the gear-box, which has the same speed reduction ratio as those already mentioned, viz. 1 : 3.86, both of the pinion shafts are situated above the propeller shaft. They are very short and of large diameter, and are mounted in roller bearings, and fitted with brake drums. The propeller shaft in this car differs somewhat in design from those in the other cars, and it is mounted on two cross-members and not enclosed in the gear-box. The drive from the main gear wheel shaft is supported by a roller bearing, and also carries a single row thrust bearing. The cross-member carrying the bearing is very short, and is of box construction of sufficient strength to transmit to the car the thrust of the large propeller which is 19 ft. 6 ins. in diameter and absorbs 540 h.p.

The other three propellers are 17 ft. 6 ins. in diameter, and absorb 275 h.p. The double gear of the after car is lubricated by means of a pump and auxiliary tank, and a special connection from the system is taken to the aft end of the car to lubricate the thrust and roller bearings.

GAS-BAGS.

There are in all 18 gas-bags, with a total capacity of 2,000,000 cubic feet. They are placed inside each of the bays formed between each pair of the main tranverses, and are attached in no way to the ship, but impart their lifting power to the ship wholly by their pressure on the underside of the upper portion of the frames. The bags are protected from the actual girders by a series of cord mesh laced on the inside of the girders. Each gas bag is fitted with an automatic relief valve, designed to blow off at a certain pressure, and nine of the bags have a manœuvring valve placed on top. These may be operated from the forward control car, and are used, during the manœuvring of the ship, for discharging gas when the ship is light for trimming purposes. Ventilation trunks are fitted between the gas-bags with their outlet at the top of the hull, otherwise the gas discharged from the automatic valves would partially remain in the keel, as the automatic valves are at the bottom of each bag. The gas-bags are composed of a very fine quality single-ply cotton fabric with rubber on the inner surface. The inner surface is completely covered with goldbeaters' skin laid on with rubber solution, and the whole is then varnished.

As it is impossible to arrange that the ship be always maintained on an even keel, and also to meet the possibility of any gas bag becoming partly deflated, arrangements have been made to lessen excessive pressures which would be set up during such conditions. A central wire is connected from bow to stern of the ship, along the longitudinal axis, through the gas-bags, tying together the transverse bracing wires to assist in this work.

The outer cover is composed of a very light linen fabric to which has been applied weather-resisting dopes before the material is made up into the necessary shape. After the cover is fitted to the ship and laced up to take as much of the slackness out of it as possible, it is again doped with a view to ensure its being absolutely taut and rainproof.

Control Car.

The control car, or navigation car, is situated and adjoins the forward engine car. There are situated all the necessary instruments—steering wheel and elevator wheel, control toggles for operating gas and water valves, and trail ropes. Voice or telephone tubes to engine cars and various parts of the ship, engine-room telegraphs, and the wireless operator's cabin, all the wires, of which there are nearly 50, passing between the hull and the car, are enclosed in a stream-line fabric casing. The rudders and elevators are operated from this car, with an auxiliary or secondary control from the after car. They are all hand controlled, but as they are balanced, the actual working of them is very light. The controls are designed for working the rudders and elevators from 20° hard over to 20° hard over, and are arranged so that all of them can be worked together, or each of them worked independently. Special arrangements are made to fix the planes in neutral positions so that repairs, if necessary, can be made in the air.

Particular care was taken to provide the ship with the most effective mooring and handling arrangements. A sketch is reproduced showing these " all down." The ship does not carry all these in flight; The handling ropes are fitted with toggles on the end, and are removed by the handling party before the ship is finally let go. The fixed cable which then hangs down is hauled up and stowed along the corridor.

A special drogue is also fitted for mooring over the sea. This is fitted with a tripping gear which enables it to be slipped instantaneously.

Preparations for Voyage.

From the time the ship was nearly completed the possibility of the Atlantic cruise was contemplated, and naturally accelerated the work. The ship had not done a hundred hours' flying before the Atlantic trip, but the flights done were successful and of long duration. These flights comprised a flight from Inchinnan, the constructors' works, to the Airship Station at East Fortune, one of 20 hours ; another similar period on patrol duties, and a flight of over 50 hours' duration, mainly over the Baltic Sea, the distance covered on this trip amounting to nearly 2,500 miles. Little time elapsed between the completion of the satisfactory Baltic trip before preparations were made for the Atlantic. Special foodstuffs were taken aboard, extra drinking water tanks were fitted, and special cooking arrangements made in the wing and forward cars, which comprised a fitting on the exhaust manifolds. Hammocks and sleeping bags were provided, the former being of a light net pattern, and light double lining Capac sleeping bags to suit. Watch and station bills were arranged for the whole crew, and parachutes and harness tested and checked, the parachute harness being incorporated in the flying combination suits ; additional necessary instruments were fitted and the compasses corrected.

Preparations in U.S.A.

A party consisting of two officers and eight men were sent to America to make arrangements for the mooring of the ship. A suitable landing field had to be chosen, and the necessary mooring laid down and made. This mooring consists of what is termed the three-wire system of mooring, and is arranged as follows :—Steel rings are attached to eye-bolts sunk in concrete bases in the ground at the apices of an equilateral triangle, 800 ft. apart. Three wires are spliced to a central ring, and led through blocks at the apices of the triangular base to a swivel block at the mooring point of the ship, 200 ft. above the ground. The ring was free to move within the triangle formed at the base, and the wires were always kept taut, no matter which way the ship was blown or yawed. This proved a satisfactory method, as the ship remained and behaved well on this mooring for four days.

Gas tubes for replenishing were grouped in sections in a circle around the mooring base, and two travelling engineers' workshops were handy. Petrol was stored in special tanks on motor lorries, and electrical pumping plant was installed. The local fire brigade engine was used to pump water into the ballast bags, and proved a quick method. The utmost care was taken to ensure that the specific gravities and flash points of the petrol and oil were the same as on the outward voyage, so that the carburetter and oil pump systems would remain the same. Spare engine parts, gas valves, accumulators, and a stock of special food was taken over for the return journey, and a landing party, consisting of American soldiers, with a sprinkling of the U.S. Airship Section, was trained for the landing.

THE OUTWARD VOYAGE.

East Fortune.

The date and time decided upon was 2 o'clock in the morning of Wednesday, July 2nd, 1919. Press representatives were notified the day previously.

At midnight the crew were all ready at their stations, and ready to receive final instructions. One o'clock in the morning found the engineers running the engines, testing oil and water circulations, and having a final scrutiny of their respective cars. At 1.30 the ship was taken from the shed, and 19 minutes later was in the air, actually starting 18 minutes in advance of scheduled time.

There was slight rain and mist as the ship left the landing party, and had disappeared in the darkness and low-lying clouds at 100 ft. Emerging from the clouds at 1,500 ft., and heading for the Firth of Forth and Edinburgh, the lights of Rosyth could be seen through a break in the clouds. Wind 20 m.p.h. from the east, course true. Rather bumpy owing to flying low, the wind being broken up by mountains in the north, causing violent wind current and air pockets. Height controlled, mainly owing to ship being loaded to almost the maximum, almost 16 tons of petrol alone being on board. This meant an anxious time for Major Scott, as he had to keep the ship as low as possible and at the same time pass over Northern Scotland, where the hills rise to 3,000 ft.

6 a.m., July 2nd.—Airship running with four engines at 1,600 revolutions, forward engine resting. Air speed, 38 knots. Land miles made good, 56·57. Course, 298°. Wind, N.E., 15½. Height, 1,500 ft. Clouds rising higher, and ship in clouds. Capt. Harris (Meteorological Officer) estimates clouds up to 5,000 ft.

7 a.m.—Ship now between clouds, a slight drift to south.

7.30 a.m.—Breakfast : Cold ham and hard-boiled eggs, bread and butter and hot tea. Breakfast in two watches generally of about 15 each. Complement on board, 32 persons. Latest jazz tune on the gramophone as an appetiser, " Wild, Wild Women." Watches change over, and relieved crew to breakfast at 8 a.m. prompt.

A record of the ship's log will not be referred to, but impressions created will be given at various phases of the voyage. Any outward incident or interesting report will be mentioned.

The crew are now settling down, the majority are hoping for success. They have every confidence in " Scottie," as the Captain is respectfully known, and are setting out with the keen determination to *do* it.

Engineers enter up their respective logs every 15 minutes, and by the time they have gone over all machinery bearings, oil and water temperatures and pressures, and entered up their log it is almost time to start over again. A most careful watch is maintained, and, as may be imagined, the engineers are ready for their relief, to get away from the noise of the engines and ringing of machinery.

11 a.m.—Running on two engines only, and making 30 knots. This is the most economical speed, as only 25 gallons of petrol are consumed per hour at 1,600 r.p.m. Major Cooke, the navigating officer, on top of ship taking readings. In wireless touch with East Fortune, Clifden, and Ponta Delgada, and messages of good luck received from Air Ministry, H.M.S. " Queen Elizabeth," and others.

11.45 a.m.—Lunch : Beef stew, potatoes, chocolate, and cold water. Relieved crew turn in their hammocks, slung in position, along the keel, each person sharing one hammock with his opposite relief, but each having their own parachute and knowing its exact position.

Plenty of exercise can be obtained as the keel is about 600 ft. long, and to give a better idea, it is a difficult matter to recognise a person just over half way along ; more so as all are dressed alike.

Sea occasionally visible, deep blue with a big swell. Rather unpleasant on a sea-ship but not noticeable in the airship. The shadow of the ship in the clouds, with the sun overhead, gives a remarkable rainbow effect : one complete rainbow encircling the airship itself and another encircles the shadow, the colouring being extremely vivid.

3.45 p.m.—Tea : Bread and butter, greengage jam, and two cups of hot tea, the water being boiled on the exhaust pipe cooker fitted on forward engine. Fruitarian cake tried for first time—very nourishing but rather sickly taste.

Capt. Greenland vainly trying to find one who used his toothbrush for mixing the mustard for lunch !

6.40 p.m.—Height 2,000 ft. over clouds, with a blue sky above. In wireless communication with battle cruisers " Tiger " and " Renown," verifying position and receiving weather reports.

7 p.m.—Driving through clouds at 3,000 ft. on all five engines. Ship now very heavy owing to change of temperature, and is 12° down at the stern. This is usual in the night, and during the day the nose of the ship is down, owing to the ship being light. Driving down to keep to the desired height to avoid increasing gas pressure and consequent loss.

The sun is now low down on the horizon, making it difficult for the helmsman (the late Major Pritchard) to see.

9 p.m.—Now dark and slightly cold, mainly owing to clouds. Rather bumpy and between cloud strata. All through the first night over the Atlantic the usual airship routine is kept. Navigating, steering, elevating, and keeping the engines at their best speeds being maintained, watch by watch, the same as during the day. The airship is lighted throughout, but the Radolite paint on the instruments and petrol tanks is so luminous that lighting is almost unnecessary.

8.20 a.m., July 3rd.—Clocks put back for correction. Now over half-way between Ireland and Newfoundland, over the westbound steamship route from Cape Race to the Clyde, and crossing the eastbound route from Bellisle to Plymouth.

2 p.m.—Engineer on starboard amidship engine reports engine water leak. In tightening a slight leak on the water jacket the thread stripped. An effective repair was made by plugging the hole with chewing gum and bolting a copper plate across with the adjoining studs on each side.

5 p.m.—Capt. Harris unwisely shuts his hand in the door of the wireless cabin. Injury painful but not serious ; language not audible as the forward engine was running !

6.30 p.m.—Gradually getting into shallow depression. Very rough sea. Wind velocity 45 miles and heavy rain. All windows closed. Ship steady. Major Scott decides to climb out of it, and at 3,400 ft. all clear. Black angry clouds giving way to small grey.

8.30 p.m.—Sun setting. Extraordinarily interesting sky changes, changing colours as the sun gradually disappears. A stowaway discovered—a black cat—which was smuggled on board by one of the crew for luck.

4.30 a.m., July 4th.—A wonderful sunrise and glorious soft colourings. Height, 1,000 ft. Bright blue sky and light fog underneath. Heavy swell on the sea. Fog bank ending abruptly 10 miles away to the south. Sun shining on an iceberg. roughly about 300 yds. square and 150 ft. high, and another big one in the distance.

8.15 a.m.—Fog clinging to the water, which is evidently very cold. Underneath on the port beam there is a long stretch of clear blue sea sandwiched between wide expanses of fog on each side, looking like a blue river flowing between two snow-covered banks.

9 a.m.—Over a large icefield, the sea being full of enormous pieces of ice. the ice being blue-green under the water with frozen snow on top.

1.50 p.m.—Land in sight. Spotted by Major Scott on starboard beam. Few small rocky islands visible momentarily through clouds. Altered course to inspect and eventually located north-west coastline of Trinity Bay. Time from Ireland to Newfoundland, 59 hours.

2.30 p.m.—Over Newfoundland at 1,500 ft. Message from St. John's to say Mr. Raynham had gone up to meet ship. Replied giving position. Ran into dense fog.

7.45 p.m.—Passed over tramp steamer "Seal," bound for Sydney (Nova Scotia) from St. John's, the first seen.

2.30 a.m., July 5th.—Very dark, clear night. Lights of Whitehaven showing brightly on starboard side. Strong head wind, and making no appreciable headway.

7 a.m.—Altered course to avoid wind barrage blowing up coast. Crossed over coast at Goose Island and Country Harbour. Miles and miles of endless forest, small rivers and lakes.

12.30 p.m.—Lunch. Petrol question serious. Have 500 miles to go to New York. Signal sent by Lt.-Com. Lansdowne, U.S. Naval Airship Service, the American Representative to U.S. Authorities, to requisition destroyer to stand by.

3 p.m.—Passed Haute Island in Bay of Fundy.

3.30 p.m.—Having bad time in electrical storm. Altered course east to dodge the storm.

7.30 p.m.—Clear weather again. Nova Scotia well behind and heading straight for New York. Very fine electrical disturbance at sunset.

9.30 p.m.—Another thunderstorm. Changed course again. Unfortunate owing to petrol supplies running short.

4 a.m., July 6th.—Sighted American coast at Chatham.

5.30 a.m.—Major Scott decides he can complete the journey under own power, and lands at Hazelhurst Field, Long Island, at 6.45 p.m. G.M.T. or 9.45 a.m. United States summer time.

Total time of voyage, 108 hours 12 minutes. Many congratulatory messages from England, from His Majesty the King, Air Council, Air Staff, and others.

ARRIVAL IN U.S.A., AT ROOSEVELT FIELD, LONG ISLAND.

The ship arrived under good conditions, which, unfortunately, did not improve during the day. The landing party consisted of relays to the number of 500 to 600 men of the U.S. Air Section, and a good portion were black men.

When the ship was held down and sufficient men placed on board to take the place of the crew, the "unwashed and unshaven" party left their craft, receiving a tumultuous reception from the huge crowd awaiting.

The crew were then taken to their respective land quarters to rest, and later taken in cars to a banquet held in their honour at Garden City.

A terrific thunderstorm broke overhead at 1 p.m., and the ship being without sufficient gas at the time, although refilling operations had begun, simply sat down on the ground. The rain lasted until almost 9 p.m., when the ship was let up on the mooring. There it rode all night in safety and, being under the searchlights, made a wonderful picture, being visible for many miles. A strong wind had sprung up early in the morning, and the ship being very light, owing to the sun, difficulty was encountered in hauling it down. In the consequential operations part of the bow at Frame 3—the mooring point of the ship—was damaged, but after wooden stiffeners had been placed as a temporary repair, it was decided that the damage was almost negligible and would not affect the flying performance.

During the four days that followed, the gassing and refuelling of the ship were carried out, the ship being let up on the mooring for the night. Nothing worth mentioning was done to the engines and machinery, as the necessary inspections of the power units revealed no cause. The engineers cleaning down and preparing for the return journey. The crews worked in the forenoon only, the rest of the day was spent on leave, and owing to the generosity of the people, cars were placed at their disposal for taking them into New York for sight-seeing.

Return Voyage.

At 10 p.m., on July 9th, Major Scott decided, in view of the strong wind coming and the unfavourable ground conditions, to leave that night, and the crew were warned to be at their stations at 10.30 p.m. Hurried leave-takings were made, and the last stores and food to be carried were placed on board. Gassing was carried on until the last minute on the ground, and at a few minutes to twelve the order to ballast up was made. The wind was now strong and gusty, and the ship left the ground with only three of the engines started, and quickly rose to 2,000 ft.

Steering straight for New York, the city being easily visible at that distance—20 miles—owing to the brilliant street lighting, the ship arriving over Fifth Avenue, Times Square, and Broadway at 1 o'clock in the morning, the square being a blaze of lights. Huge quick-change advertising signs are concentrated at this point, the upturned faces of the pedestrians being plainly seen. The air over New York felt disturbed, partly owing to the approaching cyclone, of which warning had been given, and partly owing to the heat arising from the city.

1.10 a.m., July 10th.—Turned about New York, and steered for Scottish base. Wind behind and speeding at 74 miles per hour. Weather conditions distinctly favourable for return journey. Wind S.W. at 35 m.p.h.

2.17 a.m.—Crossing American coast. Four engines running, the fifth resting.

9.15 a.m.—Outward 430 miles and going strong. Sorting out mail. Letters and parcels of various descriptions, and copies of newspapers for delivery. Making 72 knots or 83 m.p.h. Major Scott, if all goes well, will make for London, and see how long it takes from Broadway to Piccadilly Circus, the heart of one city to the other.

12 noon.—Lunch Cold sausages and pickles, stewed pineapple and ration of rum. Weather fine. Wind S.S.W.. 40 knots, sea very rough. Ship very steady. Wireless messages received and transmitted to America.

4.50 p.m.—900 miles from New York in 16 hours, 1,850 miles from Ireland, and exactly one-third across.

6.15 p.m.—A five-masted schooner under full sail under starboard beam. An interesting contrast between the old and new—the sailing ship and the airship. Getting much colder.

11 p.m.—Roller bearing aft of clutch bearing on the forward engine in the after car very hot. Unsuccessful efforts to cool by packing with grease and flooding with oil. Breather cowl removed from gear box and length of water hose connected to cowl. Cowl placed outside the car and stream of air directed on to bearing, and cooled in less than five minutes.

4.20 a.m., July 11th.—Foremost of two engines in aft car breaks down. Connecting rods fractured owing to bolts shearing, forcing holes through water jacket and sump. This breakdown was due in no way to the constructors, but the engineer, owing to a roll on the ship, slipped and fell against the clutch lever, disconnecting the engine from the propeller. The engine, being on full load, immediately raced up, and the resulting stresses caused the fracture. The governor gear had previously been disconnected.

6.40 a.m.—Altered course to N. 30 deg. E., height reduced to 600 ft. to get under clouds, finding by calculation that below the clouds is a northerly wind, and at 3,000 ft. the wind is S.W., caused by Gulf Stream. Rise to 3,000 ft. Wind S.W. Even better wind higher up, but Major Scott decides to keep at 3,000 ft. to avoid losing gas.

12.30 p.m.—Lunch. Meal-times being welcomed, and giving the more responsible members of the crew a much-needed interval.

4.30 p.m.—At 3,000 ft., speed 32 knots. Major Scott brings ship down to 900 ft. to get a glimpse of water to check speed, but abandons attempt. Passed five distinct layers of cloud strata. Major Scott decides to give up the attempt to fly to London, in view of easterly depression, and one engine being out of commission. Making for East Fortune instead.

7.05 p.m.—Passing through wet rain clouds. Raining heavily since 5 o'clock. Major Scott takes ship up to 5,000 ft. to get out of it, but with no success, and reduces height to 3,000 ft. again. Very cold and dark. All windows and doors shut.

12. midnight.—Still raining, but still very confident, and wonderful feeling of safety in the ship.

12.45 a.m.—July 12th. Weather clearing. Sea visible at 2,500 ft., and soon afterwards a magnificent sunrise. An indelible impression of colour and beauty.

6 p.m.—750 miles from East Fortune. Air speed 32 knots. Unable to plot position for 24 hours. Wind consistent in strength and position.

12.30 p.m.—Height 5,000 ft. Visibility at its maximum, approximately 80 miles=160 in diameter or an area of 19,000 square miles, and not a ship to be seen.

5.30 p.m.—Great excitement as two trawlers are sighted on starboard beam. Getting in touch with signal lamp but no reply. Down to 3,000 ft.

6.57 p.m.—Passed out of squall. Low black clouds and rough, confused sea. Ship very steady.

7.15 p.m.—LAND IN SIGHT. First spotted by Col. Hemsley, of U.S. Army Aviation Department, 7-10 miles away. Alter course to make land. Wireless masts of Clifden in sight. Crossing at the same spot as Sir John Alcock and Sir Arthur Brown. A strange coincidence.

8.15 p.m.—Heading in over mountains which are at this spot 2,900 ft. high. Wild and rugged coastline. Magnificent cloud panorama appearing—lakes, harbours and green fields, the prettiest picture the whole voyage. Height, 6,000 ft.

9.10 p.m.—Two-seater aeroplane from Castlebar waving a welcome—making for Belfast and East Fortune.

11.20 p.m.—Messages from Air Ministry to land at Pulham. Height 5,000 ft. Isle of Man. Liverpool, 2.45 a.m. ; Derby, 3.55 a.m. ; Nottingham, 4.15 a.m., direct to Pulham.

5 a.m.—Wireless message from H.M. the King : " I congratulate you all on your safe return after completion of your memorable and, indeed, unique Transatlantic voyage.—George R." Other messages arriving.

6.20 p.m.—Over Pulham Airship Station.

6.57 p.m.—*Landed.*

Time taken from Long Island to Pulham, 75 hrs. 3 mins., or 3 days, 3 hours, 3 minutes.

The ship finally flew to East Fortune and over London four days later. It was then overhauled, and unfortunately smashed up at Howden, E. Yorkshire, whilst being held out on the landing station. The ship crashed into the cliffs near Scarborough on January 28th, 1921, in the fog, smashing the aft and forward cars and placing the power units out of order. It would seem from the facts available that this catastrophe was helped by the policy of being "penny wise and pound foolish," for there is little doubt that the accident would not have occurred had the station been properly equipped with a mooring mast and various other handling gear, the cost of which would have been nothing compared with the loss of a quarter of a million.

The tank shewn in the foreground of one of the lantern slides was interesting because of the useful purpose it served, namely, to assist in opening and closing the shed doors, the operation being as follows :—

Eyes were spliced at each end of a length of "ten-ton wire," and secured to each door. Then the wire was taken through a series of blocks and pulleys fastened to wire slings, hitched to bollards in the ground. The wire rope was drawn by the tank in its progress across the landing ground, both doors being opened or closed at the same time.

The original method was by straight spur gearing, operated by twin capstans mounted on the door platforms through gear wheels fixed on the door axles. Eight capstan bars were located in sockets in each capstan head, each bar being approximately 10 ft. long, and pushed by men drawn from the handling party. The men on the extreme end of each bar walked about two miles in the opening or closing of either door !

Not less than 45 minutes were taken by the capstan method in the opening of the doors, and only 10 minutes with the assistance of the tank.

Each door, of which there were four to each shed, weighed about 200 tons.

DISCUSSION.

Mr. L. T. Godfrey-Evans, M.S.E., praised the skill and ingenuity shewn in the design of the details of the various sections of the structure, the correctness of which were fully borne out by the successful behaviour of the ship during its tour in crossing the Atlantic to and from America.

The speaker referred to the transverse sections, all of which were of the circular form, which struck him as not in keeping with his conception of natural laws or of experience in engineering construction. For instance, in passing through a solid, more or less dense, a cylindrical body with a revolving action was the best suited for advance, but such a body passing through a light medium, as air, would tend to roll, imparting stresses which would be absent in a shape having a transverse sectional form more in keeping with natural conditions. The " flying fish " has a section suited to two elements. Then there were the familiar forms of birds with outstretched wings in flight which suggest the triangular section, which the speaker suggested would give a lighter, stronger and more adaptable skeleton framework for a more efficient airship.

The speaker then mentioned an aeroplane he had designed in 1909, under three patents, having a centre of gravity which automatically moved forward or backward, and so occupied a relative position according to the velocity of the aeroplane. At the maximum velocity the centre of gravity would occupy the extreme front, and at the minimum velocity it moved to a point near to the centre of area of the planes. The wing area being a minimum at maximum velocity, and a maximum area at minimum velocity.

Mr. W. D. Kitching, A.S.E., asked whether, in the author's opinion, airships would be of any commercial value in the future.

Mr. F. C. Evennett, said :—

Because of the various disasters that had overtaken airships when moored over or forced to descend to the surface of water, he was interested in the author's description of the drogue method of sea anchorage. He considered that all airships which were intended for oversea flights should be so constructed that they stand some chance of being able to alight on the sea should it become necessary.

Taking the case of an airship in the single predicament of a gas leakage whilst over the sea, it seemed a miserable confession of the engineers' impotence that it must become a total wreck because it cannot alight. A few hours' riding on the water might enable a repair ship to arrive and supply gas or render such other assistance which would enable the air voyagers to carry on or get back to a base. Therefore it would seem that the attention of airship designers should be focussed on this problem in particular.

Having had some experience of bad weather at sea, he appreciated the danger and difficulty of any descent to the surface on the part of a rigid airship, but there was no need to forego the chance of safety under favourable conditions because of a perhaps impossible descent in bad weather.

Last year's tragedy on the River Humber was a case in point. It was reasonable to suppose that the disaster to the R. 38 might have been averted had the vessel been resting on floats which were an integral part of the airship's structure. Any system of floats would, of course, have to be capable of maintaining a head-to-wind position of the airship, be stable and capable of safely supporting most of the total weight. Taking the total laden weight as 60 tons, 2,000 to 3,000 cubic feet of float capacity should be ample, and as the floats might also be used as cabins, etc., they would not involve any great addition to redundant flying weights. The most important condition of such floats would be that they would readily cause the ship to assume and maintain its head-to-wind position, and from some experiments he had made with small models in 1919 it seemed that the float idea was practical. Three floats were used, the forward one being on a longitudinal axis, and the two smaller after floats on a common transverse axis : in plan something like capital T. The latter could be mounted so that they could be rotated to a longitudinal axis when in flight to diminish head resistance. He would like to have the author's opinion on this suggestion.

Whilst engaged with Messrs. Beardmore & Co., the speaker had made material estimates for the R. 34, and he was greatly pleased to learn of the success of our aerial pioneers and to realise that our countrymen were still ready to " go one better " than their competitors.

Mr. A. S. E. Ackermann, B.Sc. (Engineering), M.Cons.E., wrote stating that he was particularly interested in Mr. Turner's description of the type of door used for airship sheds and the method of operating it. Having to ballast such doors with 100 one-ton blocks of concrete, costing about £3 each, in order to prevent their being blown over when open, thus adding 100 tons to the weight to be moved when the doors were opened and shut, doing this opening and shutting by hand power, thus causing a number of men to walk *two miles* each during the operation, or having the expense of keeping a tame " tank " to do it, was not a credit to one of the most modern branches of engineering. In March 1916 he designed a door for airship sheds which met with the warm approval of Admiral Sir Percy Scott and all the many engineers and constructors of airship sheds who had inspected the working model, except those at the Admiralty, and this in spite of Admiral Scott having asked for the model to be made in order to assist him to bring the matter to the notice of Mr. Balfour, then the First Lord of the Admiralty, Commodore Seuter (then in charge of airships), and Mr. Simms the Director of Works of the Admiralty.

The principle of this door may be understood from the following :—

Place a ladder in the ordinary position against a wall. This represents the door in its closed position. Move the foot of the ladder slowly away from the wall then the top end of the ladder slides down the wall and ultimately the ladder will lie on the ground at right angles to the wall. This represents the door in its open position a recess being formed in the ground to receive it so that its then top surface is level with the ground. The two top corners of the door are provided with flanged wheels which run on two vertical rails, one on each side of the opening into the shed. The bottom of the door is provided with several flanged wheels running on a corresponding number of horizontal rails parallel to the axis of the shed. Four wire ropes are attached to the four corners of the door. Those attached to the top corners pass over grooved pulleys near the top of the opening into the shed. Those attached to the bottom corners do not pass over any pulley. The two ropes on the right of the door are joined at their free ends and so also are those on the left of the door. From each of these two junctions a single hauling rope is taken to a drum. Hence the arrangement of ropes on each side of the door may be likened to a block type Y lying on its side thus < The door opens by gravity in about three minutes and can be shut by a 20 H.P. electric motor in about ten minutes when part of the weight of the door is taken by counterweights. No ballast is required, and the door, when open, is completely out of the way of the airship and wind, and when shut it could not be blown down without the shed having to be blown down too.

In addition to its merits as a large door, it enables a great saving of steel to be made where two or more sheds are required at the same base, *e.g.*, at Howden three such sheds were erected, spaced apart so as to provide room between them for the half-doors (of the ordinary type) when the doors were open. As these sheds are about 700 ft. long and 100 ft. wide, there is a considerable thrust due to the arch of the roof, and to take this thrust lean-to's have to be provided. These are about 35 ft. wide at the ground level, and taper to nothing about 80 ft. from the ground, but they have to extend the whole length (700 ft) of the shed, and consequently contain about 30 per cent. of the total amount of steel used in the whole shed. With the writer's type of door the sheds can be built in contact side by side, and then only two lean-to's are required for the two outer sides of the outer sheds. Hence, instead of six lean-to's having to be constructed, only two are needed, thus saving, say, twice 30 per cent. of twice £100,000 (the cost of one complete shed) on a total expenditure of £300,000, or a total saving of £60,000. In arriving at this estimated saving, allowance has been made for the fact that if the four inner lean-to's were done away with, some stiffening of the vertical stanchions might be necessary. But, again, there would be a saving of the weather-proofing material.

REPLY BY THE AUTHOR.

The author was impressed by the form of transverse section suggested by Mr. L. T. Godfrey-Evans, but considered that the designers and constructors had in mind a form that had been proved and tried. Airships had to be built for severe duties and for the longest possible wear. The production of such was an urgent, vital necessity, and the factor of safety must be known.

A "movable centre of gravity" was used in effect during flight, by pumping petrol fore or aft, but it was a long and tedious operation. With reference to a centre of gravity which would automatically move according to velocity, this would be a difficult problem in design owing to the length entailed and the weight. On an aeroplane, such as Mr. Godfrey-Evans suggested, the power unit could change its position on a longitudinal axis according to the power delivered.

In reply to Mr. Kitching *re* the commercial future of airships, the author said that in this country he considered there was little or none at present on account of financial difficulties. The airship's only possible opportunity was for trans-oceanic voyages of long duration or for long journeys to our distant Colonies. For European journeys multi-engined aeroplanes could do the journeys rather more quickly, and the maintenance cost was small in comparison. In other countries the advantages of airships were manifold. The weather conditions were more favourable. The necessity of providing emergency or supply stations for aeroplanes was not necessary for airships. Airships were also in the favourable position of being able to carry out repairs whilst in flight. The comfort of passengers, too, could be provided for better in airships, an important factor on long journeys, and the passenger saloons and compartments were well away from the engine and machinery cars.

In reply to Mr. F. C. Evennett, it was the author's opinion, in view of his personal experiences of airships, that the greater danger to airships was only when on or near the ground. Airships were easily moored over the sea on the drogue system. They were easily and safely moored to ships at sea or even taken in tow. Riding on a wire at a single-point suspension, made the ship easily controllable on the helm and elevators, and it was easy to keep the head to the wind.

The author had never known of an instance of a rigid airship having to "land" owing to gas-bag leakage. Even had that been the case, an airship was designed to fly with a number of gas-bags deflated, provided the necessary lift was still in the remaining gas-bags and presuming the ship to be afloat on what would be termed " buoyancy bags," as was suggested. The problem of " taking off " from the sea alone would be a matter of considerable difficulty. The suction effect on the buoyancy bags would mean jettisoning an unreasonable quantity of ballast to make the ship sufficiently light. The risk of engaging the propellers for that extra lift would be practicable only on a smooth sea. A sea with a " swell " would make the airship roll rather badly on the " buoyancy bag " suspension, and would impose severe stresses amidships, where usually important power units were disposed.

The difficulty of keeping head to wind was easily anticipated as the stern would not easily swing round, but would drag, causing the ship to heel over.

With the drogue system of mooring at sea and also on the " three-wire " mooring mast on the ground, ships had been known to ride out for weeks in winds up to 45 miles per hour with perfect safety.

Monday, December 4, 1922.

T. J. GUERITTE, B.Sc. (Paris), M.Soc.Ing.Civ. de France,
PRESIDENT, IN THE CHAIR.

WAVE POWER TRANSMISSION.

By W. DINWOODIE.

Since the transmission of power is of such importance in engineering, every means whereby that transmission may be accomplished is of interest to engineers. In this paper a system of power transmission is described which is still in its infancy, but whose development up-to-date gives reason to believe that in appropriate fields of operation it will prove to be an advance on those methods practised to-day.

The system was invented by a Roumanian mathematician and engineer, George Constantinesco, whose attention was attracted to the possibilities of the transmission while investigating the mathematics of acoustics. Financial backing was forthcoming through Mr. W. Haddon, of London, license to manufacture plant working on such principles being granted to Messrs. W. H. Dorman, of Stafford. To Mr. Haddon, as owner of the British patents and to Messrs. Dorman, the writer is indebted for permission to collect information for this paper, and for much assistance in the preparation of illustrations.

In the wave system of power transmission, power in the form of vibrations of the particles of an elastic medium is transmitted through the latter in waves, and converted in a suitable receiver into useful effort. For this purpose a generator operated by a suitable prime mover is used to produce waves in the transmission column, the latter being, in the simplest case, an uninterrupted column of the medium employed, suitably enclosed and extending from the generator to the machine or tool to be operated. In practical developments of the system, water or a suitable oil have been the media selected, water having the advantage of economy as well as giving a high transmission efficiency.

In order to outline the principles governing the operation of the system, it is necessary to deal with the phenomena associated with wave motion, and the differences which exist between such a transmission and those which depend upon the flow of fluids through pipes and suitable orifices.

When a body executes a motion at regularly recurring intervals of time, and when such a motion is in addition periodically reversed in direction it is said to be vibratory. An example of such a motion is that of a point describing a circle with constant angular velocity, as seen by an observer standing at a distance from the point and in the plane of the circle described. The point will appear to pass through its mean position with a maximum velocity, from that instant being retarded until at the extreme position it is momentarily at rest. The motion is then reversed, the velocity again reaching a maximum value in the opposite direction at the mean position, coming to rest again at the other extreme.

Such a motion is spoken of as simple harmonic motion, since the vibrations which give rise to musical notes or sounds are found to be compositions of few or many of such vibrations. A wave is the motion of such a vibration through a medium, there being two types of such waves. The first, in which the motion of the particles is along an axis at right angles to the direction of the motion of the wave, are called transverse waves, and the second, where the motion of the particles is about an axis lying in the direction of motion of the wave, called longitudinal waves. An ocean wave is of the former type, as demonstrated by the motion of a cork floating on the surface. The cork oscillates up and down, while the wave progresses in a horizontal direction. The transmission of sounds in air and other ponderable media is a case of the second type of wave, and it is a wave of this nature which is employed in the transmission of power. Sound in a medium such as air is closely analogous to the transmission under consideration. Just as sounds are transmitted through elastic and ponderable media, so also may power be transmitted, in each case the elasticity of the medium together with its inertia are the properties utilised. The subsequent remarks will refer to longitudinal waves in water, though of course similar effects may be noted in any other medium.

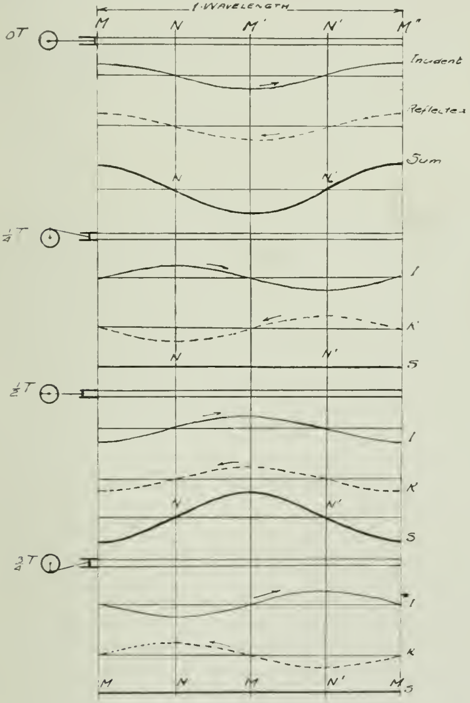
Water, for the purposes of hydraulics, has been considered as incompressible. By comparison with gases this is reasonable, but if compared with materials such as steel, it is far from the truth. The modulus of elasticity of water is about 250,000 lb. per sq. in., while that of wrought iron is nearly 27,000,000 lb. per sq. in. These co-efficients are in the ratio of 1/100 and thus with a transmission column of water enclosed in hydraulic piping the effects of the expansion of the pipe are not of great importance.

If a plunger is assumed to work against 300 ft. of 1 in. pipe completely filled with water and closed at the other end, and if the stroke of the plunger be 1 in., then the volume of the water in the tube will be (approx.) 2,700 cub. ins., and the half displacement of the plunger 0·375 cub. ins. This displacement, if brought about slowly, would give rise to an increase of pressure in the pipe line of about 40 lb. per sq. in. In this case, owing to the slow compression, the inertia of the water has very little effect.

To indicate the effect of elasticity and inertia together in the transmission of the motion of the plunger, consider the latter to move from the mean to the innermost position in 1/160th of a second, in such a manner that its motion corresponds with that due to a quarter of a revolution at 40 revs. per second. In such a case the inertia of the layers of water more remote from the plunger causes them to act as a buffer against which those adjacent to it are compressed, the compression being permitted by the elasticity of the water. At the end of the movement the water at the plunger face would be at a pressure of about 500 lb. per sq. in., while in the subsequent moments this region of high pressure would expand outwards, always against the buffer formed by the layers more remote. Thus each particle in turn along the pipeline would perform the same motion as the generator plunger at successively later instants, and a zone of high pressure would be transmitted from the generator along the column of water. In the same way, had the motion of the plunger been from the mean position in the opposite direction, a region of reduced pressure would have been formed and transmitted along the column, by the expansion of the more remote layers of water into the place of reduced pressure. If the motion of the plunger is that due to the rotation of the crank at a uniform speed of 40 revs. per second, it will be seen waves of pressure will be continuously transmitted along the pipeline, due to the continued vibration of the generating plunger. Each particle along the pipe will be executing a similar motion, but each will pass a given point in its path at a slightly later instant as the distance from the generating surface increases.

The least distance between any two particles in the same part of their paths and moving in the same direction is called the wave length. The distance through which one zone of high pressure has travelled when the next is at the plunger face is also equal to a wave length, and it follows that the product of the wave length and the frequency will be the velocity of the wave. In the case of longitudinal waves in water the velocity is found to be that of sound, *i.e.*, about 4,800 ft. per sec. This velocity is almost independent of the amplitude and the frequency, and is governed by the density of the medium and its elasticity. This is illustrated by the fact that notes of different pitch (frequency) travel at the same velocity, as do those of differing intensity. Were this not so, the effect of an orchestra heard at some distance would be confused. The same fact illustrates the pnenomenon of co-existence, or the ability of two or more waves to exist in the same medium at the same time without mutually interfering with each other. In the case of two waves meeting in the same medium, the effect on the particles at that point, is a motion corresponding to the algebraical sum of the separate motions due to the individual waves.

With a velocity of 4,800 ft. per sec., and with a frequency of 40 cycles per second, which is that commonly adopted for rock drills, it follows that the wave length is 120 ft. Just as sounds are reflected under suitable conditions, so are waves in an enclosed column of water. The effect of this reflection is shewn in Fig. 1. The first set of waves indicate the state



THE FORMATION OF STATIONARY WAVES

FIG. 1.

of the pipeline at the moment when the plunger is in its innermost position and the following three sets that at intervals of $\frac{1}{4}$ cycle. For clearness the incident and reflected waves are shewn separately and the sum of their effects is indicated by the thickened curve. It is seen that at all points in the cycle, the pressure at the points N and N' is permanently at the mean value for the system, while at M, M' and M", the pressure varies over a range which is twice that of the incident wave. The condition in the pipeline at various instants throughout the period is shown in the diagram appended. (Fig. 2.) This result, however, is reached on the assumption

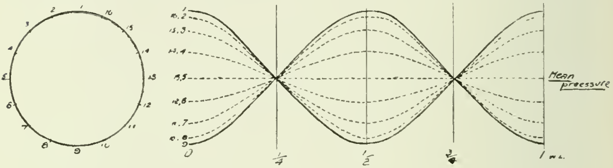


FIG. 2.

that beyond being reflected and setting up this stationary wave, the continued reflection has no other effects. In the case of a pipeline of one wave length (Fig. 3), it is seen that, starting with the generator plunger at the innermost position, after three cycles the first zone of high pressure will have been reflected to the plunger face at the moment that the third is leaving it. The effect of this super-position of waves is to cause this third wave to be propagated with twice the amplitude, and twice the pressure range of the first wave. In the same way, at the fifth stroke, this wave will have been reflected, and the fifth wave will be of thrice the original amplitude. This sequence will be repeated with the result that after a very short interval of time, a burst would become probable. Since this is the condition in practice when a generator is running with all the machines operated from it closed down, it is very necessary that some means should be devised to overcome the tendency to burst. This is obviated by placing in communication with the pipeline near the plunger a vessel filled with water and known as a capacity. (C in Fig. 3.) On the inward stroke of the plunger, in addition to propagating a zone of high pressure along the pipeline an inflow of water to the capacity is brought about, with a corresponding rise of pressure therein. The energy stored during this half cycle is returned to the system during the following half revolution of the generating crank, while the volume of the capacity, having regard to other factors, is so designed that when a stationary wave of the desired amplitude has been produced, the capacity is capable of taking up during one-half cycle the whole of the output of the generator, and returning this energy during the following half-cycle. Under these conditions the power expended is that necessary to maintain the stationary wave and to replace the energy dissipated by internal friction, etc.

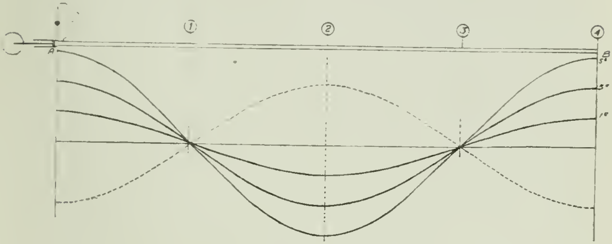


FIG. 3.

The equipment referred to in the preceding paragraph provides for the production and maintenance of a stationary wave in a pipeline, while the generator is running light. It is seen that when the pipeline is a multiple of half wave lengths, this state of affairs holds good, but when the pipeline is an odd number of quarter wave lengths, then a zone of high pressure will always, after reflection, be reaching the plunger when normally this region is at a minimum pressure. By following a line of reasoning such as that adopted in the case of the formation of stationary waves, it may be shewn that the water at the plunger face would remain at the mean pressure of the system throughout all points in the cycle, and thus there would be no flow between the capacity and the pipeline. In other words, the action of this body of water would be cut out and as mentioned previously, excessive pressures would result from the continuous input of energy to the system.

The amplitude of the pressure change along the pipeline (Fig. 3) is seen to vary from zero at points whose distance from the generator is an odd number of quarter wave lengths, to a maximum at points distant by an even number of quarter wave lengths. Hence, the operating surfaces of machines tapped in at the former points (1 and 3 in Fig. 3), will experience no pressure change and the machines will not start, while those tapped in at points (such as 2 and 4 in Fig. 3) at half wave lengths will experience a maximum pressure change and be self starting and stable in running. If, however, the motor at one wave length from the generator (4 in Fig. 3), were running and absorbing power, then a progressive wave would (in effect) be super-imposed on the stationary wave in the pipeline, and at no point therein would the pressure change be permanently zero. In these circumstances, all motors between the aforementioned and the generator would start when placed in communication with the pipe-line, though their continued running after the closing down of the motor first mentioned, would be under disadvantageous conditions with regard to transmission efficiency.

Upon consideration of the fact that the amplitude of the pressure change varies as the cosine of the phase angle, where one wave length is represented by 2π radians, it would appear that the latitude permissible in the determination of the length of the column and the distances at which machines are to be run is comparatively great. (Cosine 170° and Cosine 190° are each equal to 0·98, while Cosine 180° is unity.) When, however, a generator is operating into a closed pipeline whose length is, say, 110 ft. in lieu of one wave length (120 ft.), the tendency is for the frequency (and therefore the speed) to alter until the 110 ft. represents an even number of quarter wave lengths. Here the frequency would tend towards the value 4,800/110 or 43·7 cycles per second. This involves a speed variation in the prime mover of over 9 per cent. and since the prime mover would ordinarily be governed much more closely than this, much power would be lost in the attempt to resist the speed variation.

In the case of a pipeline whose length should be three or four wave lengths, say 480 ft., suppose that the actual length be 470 ft., *i.e.*, the same linear error as in the first case. Here, 470 ft. would become four wave lengths of 117·5 ft. To accomplish this, the speed variation would be about 2 per cent. only, thus the error permissible in view of the governing of the prime mover depends upon the ratio of the discrepancy to the total length of the pipeline, and it is found that, in most cases, with a pipeline longer than 400 ft., an error of 30 ft. is permissible, and since 30 ft. is the maximum possible difference from a multiple of half wave lengths (60 ft.) it follows that the speed variation will permit of the adjustment of any length of pipeline to a multiple of half wave lengths without undue loss of power or efficiency.

The generator used to produce the desired vibrations in the water column, is shown in Figs. 4, 5, 6 and 7. The generator described in the following paragraphs is now obsolete, but will be dealt with, since its construction is more obvious and the diagrams prepared are consequently more clear. The points in which generators of later design differ from this type, will be pointed out as they arise.

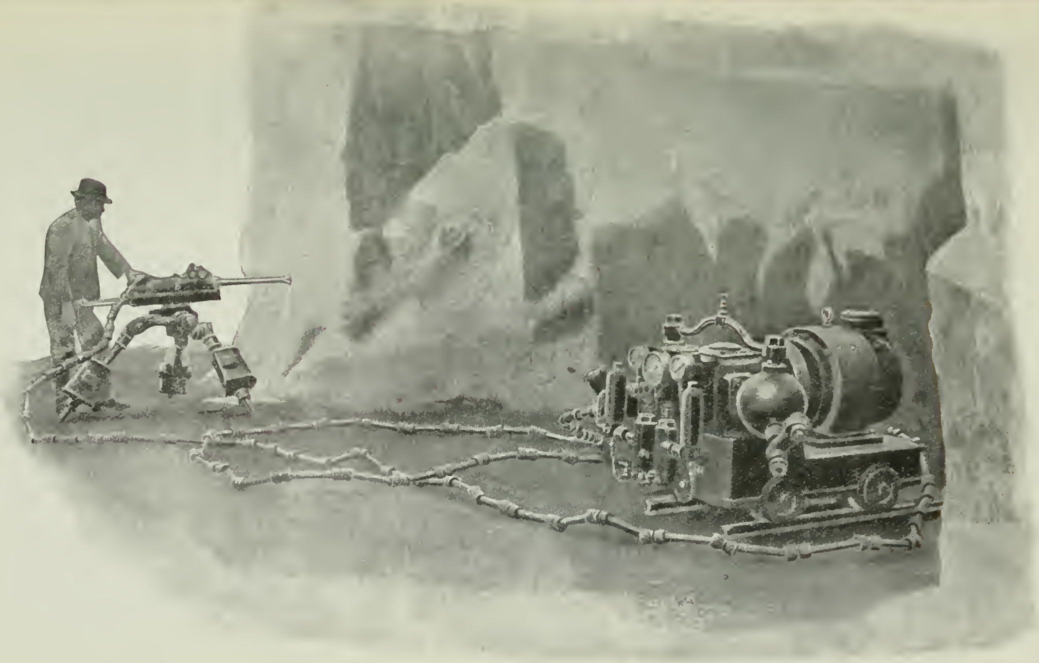


Fig. 8.

Fig. 4.

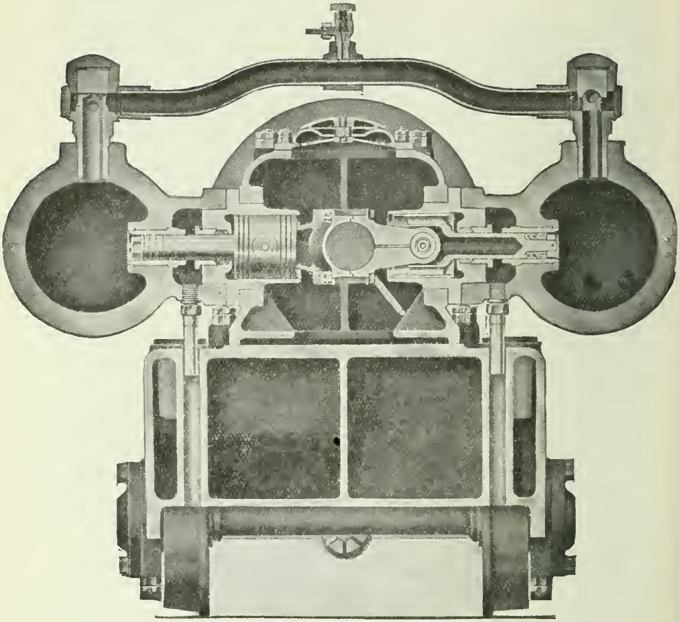


FIG. 5.

A crank case, is bolted on to a suitable bed plate, which forms two tanks, one containing water the other oil. A crank shaft having two eccentrics formed upon it and set at 180° is carried longitudinally in this crank case, the projection behind the rear journal receiving the flywheel-boss, and that beyond the front bearing having a worm formed upon it. Two connecting rods of considerable length in comparison with the throw of the eccentrics connect the latter to gudgeon pins working in cross heads which are formed integral with the plungers. The crosshead guides are of large diameter and have a projection fitting into the neck of the spherical capacities, into which the plungers work, and a flange which is gripped between the capacities and the sides of the crank case. A small stuffing box is provided in the side of the crank case to prevent leakage of oil from the latter,—the plunger itself working in a cylinder formed in the neck of the capacity where a packing peculiar to

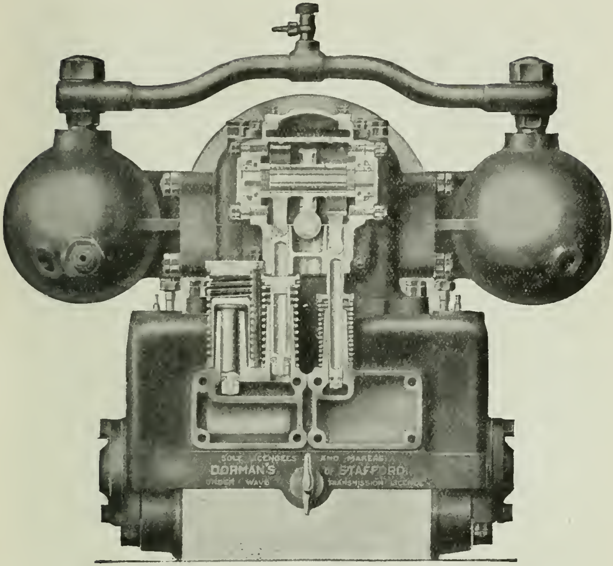


FIG. 6.

wave transmission requirements is provided. Between these two packings is situated a chamber which intercepts any leakage of water from the pipeline and prevents its penetration into the crank case. In the early type of generator (Figs. 4-6). the plungers work into spherical capacities situated at the sides of the crank case, these being connected by means of an equalising tube. In later types and larger generators the two plungers are placed in connection with one cylindrical capacity fitted transversly under the fly-wheel (Fig. 7 shows such a generator mounted with a petrol engine on a chassis built up of channel iron). The crank shaft is rotated at a speed of 2,400 revolutions per min., thus causing the two plungers to oscillate with a frequency of 40 cycles per second. The transmission line is taken away from each of the capacities. A transverse shaft is driven at a speed reduction of one tenth by means of a worm and wormwheel at the front end of the crank shaft (Fig. 6), and on this are formed two cams also opposed at 180°. These cams operate pumps of the plunger type working against springs, the right hand pump supplying oil under pressure to the bearings of the machine and the left supplying water to the system, to charge it and to maintain the minimum pressure at 100 lb. per sq. in. This minimum pressure is adopted to facilitate the elimination of air and also to keep all stresses and tendencies to leak in the same direction. The water pump has, however, to provide for variable delivery, particularly in the case of a rock drill installation, where in addition to unavoidable leaks, the water flush used with the drill has to be taken into account. This is accomplished by means of an auxiliary plunger operating against a spring loaded to lift at 100 lb. per sq. in. The plunger is of similar displacement to that of the pump plunger and is placed in communication with the delivery chamber. Water is supplied to the capacity through a non-return valve actuated by pressure difference, and when the minimum pressure in the capacity does not fall below 100 lb. per sq. in., the delivery of the pump plunger is taken up by the lifting of the auxiliary plunger against its spring, during which time the water in the delivery chamber is at a pressure not less than 100 lb. per sq. in., while at the next suction stroke of the pump, there is no intake of water, that displacing the auxiliary plunger returning to the delivery chamber. At the highest point of the water system (*i.e.*, in the centre of the equalising tube in the earlier type of generator and above the space into which the plungers work in the larger type) (Figs. 5 and 7), an air release valve of the needle type is fitted. In the event of a long pipeline, provision would also be made at its highest points for a similar fitting. The rear end of the bed plate (Fig. 4 or 7), is arranged to take a suitable prime mover, as for example, an electric motor or internal combustion engine. The three diagrams give a clear idea of the construction and general principles of the machine, while a better idea of the generator as it appears at the present time is conveyed by the illustration of the larger portable plant. (Fig. 7.)

It is seen that the generator might be regarded as a horizontally opposed high speed pump save of course, that the suction and delivery are determined by leakage, and the volume of the water flush used, in the normal case amounting to a very small quantity. The construction of the machine is simple, and such that it permits of great strength and rigidity, and the increase in size and cost for added H.P. is small. This follows from the fact that an increased capacity is obtained by using a slightly larger displacement, assuming the frequency to remain constant, and it is obvious that the weight per H.P. and bulk of the machine will be decreased greatly as the capacity is increased. With regard to the running of the machine, it is necessary that it be run up to full speed with the pipeline shut

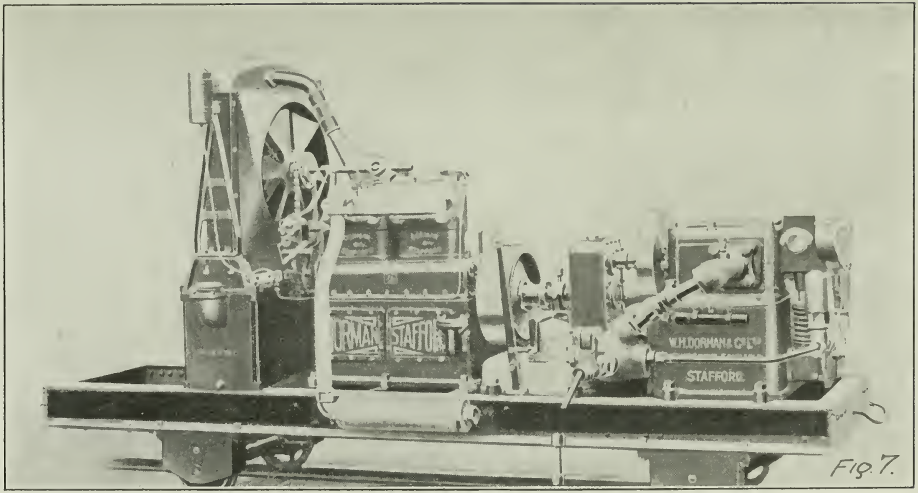


Fig. 7.

off by means of its stop cock, this also being necessary when the machine is being shut down. The reason for this is that the speed must pass through that point at which the frequency results in the pipeline being reduced to an effective length of an odd number of quarter wave lengths. During this period, (especially if the pipeline be short), there is a danger of the pipe's bursting, due to the cutting out of the spring action of the capacity as mentioned previously in the case of pipelines of such length. In starting up, the plungers thus operate into the capacity only, the air release valves meantime being left open.

The pipeline of a wave transmission installation may be built up of any piping sufficiently strong to withstand the pressures adopted and of a bore suitable for the H.P. to be transmitted. Hydraulic tubing is particularly suited to the conditions obtaining, while where flexibility is desirable or necessary, some form of flexible steel tubing such as " Flextel " is used. This is a steel tubing with special joints formed at from 4 in. centres upwards (in the case of 1 in. bore tubing). A flatted ball piece is pressed round the end of a length of solid drawn steel tubing, and a special packing ring fitted over the projection of the tube beyond the flatted surface. The piece is fitted into one of a pair of spherical seatings machined in a union piece, and secured there by a suitably machined nut (Fig. 8). Such a tubing may be bent or twisted as desired, and may also be rotated, while the seating, being one of surfaces and not a line contact, does not tend to produce grooving, and high alternating or mean pressures do not cause it to tend to straighten out as in the case of many other types of hose. A length of this pipe was tested to destruction at the National Physical Laboratory and yielded at 9·2 tons per sq. in. The walls of the tube, and not the joint or the packing, was the point of failure.

With regard to the power which may be efficiently transmitted through a pipe of given bore, the H.P. varies directly as the square of the diameter (or as the cross sectional area), if the flow in the pipe is neglected.

If as a basis for calculation, a pressure range of 100 to 1,600 lb. per sq. in. be considered, and a frequency of 40 cycles per sec., then a one inch bore tube will transmit efficiently about 15 h.p., this figure taking into account a normal flow in the pipeline due to leakage and water flush (this factor being very small). The power required to run the generator light and maintain a stationary wave in 120 ft. of 1 in. pipeline, is approximately 5 h.p., including the light load losses of the motor, the losses due to friction in the bearings of the generator itself and those obtaining in the pipeline. (This figure is derived from the electrical input to an electrically driven set, and is an average value.) It has been found by experiment that the presence of a great many joints and acute bends in the pipeline does not cause the power consumption to rise to an extent comparable with that to be expected from a consideration of hydraulics in such circumstances. This is due to the fact that the motion of the water is inter-molecular in nature, and also to the probability that the layers of water near the surface of the pipe move only with a very small amplitude, while the power is mainly transmitted through the central layers of water. Another way of looking at this point is to consider it as a transmission of pressures (and not a transmission of fluid), the transmission of pressure throughout a fluid being carried out equally in all directions.

The determination of numerical values for the power consumed in a pipeline or the efficiency of power transmission is rendered very difficult by reason of the absence of suitable measuring instruments. This system of power transmission shows a remarkable similarity to alternating current electrical transmission, but there is as yet, no equivalent for the ammeter or wattmeter. It is possible, however, to describe an early experiment carried out some time ago with the object of determining a figure to represent the over-all efficiency. A rock drill was clamped to the bedplate of a D.O.1 generator with the chuck level with the rim of the flywheel. A light pointer was pressed into the striking end of the hammer member and arranged so that it carried a scriber, which could be placed in contact with the flywheel. The drill was connected to the generator by the usual length of suitable pipeline, this being changed in nature and in the number of bends, etc., to suit the requirements of the test. The flywheel was coated with a suitable covering of powder and with the drill running, the scriber was touched against the flywheel for the shortest possible time. The drill is designed to operate by giving up this kinetic energy in the blow, and for this purpose, it is arrested at half the displacement of the waves. If the hammer be brought to rest without making a bounce before carrying out its return stroke, it is obvious that the whole of this kinetic energy will have been extracted or transmitted. The velocity of impact can be determined from the shape of the curve traced out by the scriber on the flywheel, which makes exactly one revolution per cycle. Hence, from the number of blows per minute, the weight of the hammer member and the velocity of impact, the power expended at the hammer may be computed, and in conjuuction with power input to the generator will enable a figure for the over-all efficiency to be arrived at. [These tests were carried out on a hammer which was of simpler design than that of the present rock drill and thus the figures obtained with it do not apply in the case of the later machines.] Numerically the results obtained were in the neighbourhood of 80 per cent., some results being as high as 85 per cent., these values including losses in the motor and generator and 68 ft. of pipeline.

Broadly speaking, wave transmission machines fall into two classes: (*a*) reciprocating tools and (*b*) rotary machines. Reciprocating tools, may be further sub-divided into those whose reciprocations are continuous and those whose motion is impulsive, while further classification could be made with regard to the mechanical features incorporated. As a representative tool which will serve to indicate the general characteristics of such machines, the rock drill is most suitable, more work having been put in on this tool up to date than any other, and it being that example about which most definite data are available.

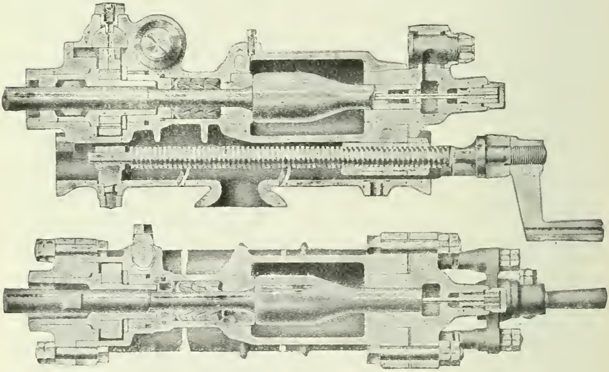
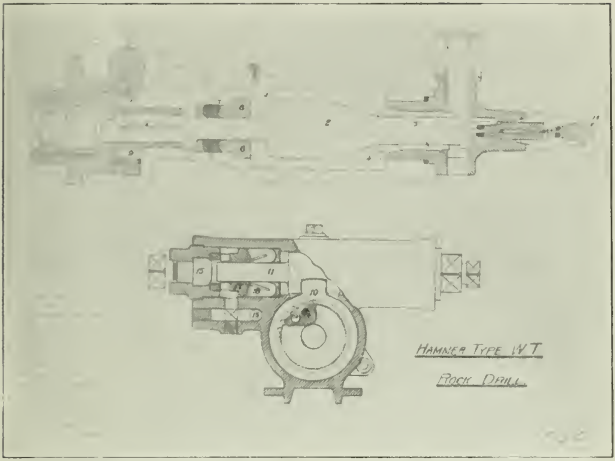


FIG. 9.

The cradle mounted rock drill of the hammer type [Fig. 9, is an obsolete type of drill, but exhibits many standard features; Fig. 10 is a sectional drawing of a more up-to-date type], consists of a body formed of three units, an inlet piece, the drill body and the chuck housing. The inlet piece contains the inlet cock, a passage communicating with the rear of the hammer member, a passage to the rotation motor, and to the rear of the water tube to supply the flush to the drill steel. The hammer is formed by a double ended plunger made massive in the central portion and having its foremost or striking plunger of less diameter than the rear. The rear plunger is carried in a special bush (3 in Fig. 10), known as a mean pressure leak bush whose functions will be dealt with later. The hammer body is surrounded by a water chamber formed in the drill body,



and fitted with an air release valve at its highest point, while the front end of the hammer works in a bush serving as a stop to the hammer's motion, a guide and a mean pressure leak bush to the front packing. The drill steel is held in the usual type of chuck and is provided with a central water channel. The striking action of the drill is as follows :—

With the inlet cock open the chamber in rear of the hammer is subjected to pressure changes due to the wave. Under the action of a zone of high pressure the hammer moves forward, making its striking stroke. Owing to the differential nature of the plungers, the water in the capacity which is normally at the same mean pressure as the pipeline, is compressed, reaching a maximum when the hammer meets the drill steel or the stop bush. As the cycle proceeds and the pressure at the rear of the hammer falls, this high pressure in the capacity acts on the differential area of the plungers and causes the hammer to execute its return stroke. This water acts as a fluid spring absorbing energy on the outward stroke and returning it during the following half cycle in carrying out the return stroke. The mean pressure leak bush in the inlet piece serves to permit of a small flow of water at mean pressure to replenish that lost from the capacity through the front packing and also permits of such a flow in both directions as to enable the effective volume necessary in the capacity to be reduced. The front stop bush damps down the alternations in pressure in the water which reaches the front packing, thus sheltering them and much increasing their life and efficiency. The design is such that the hammer system will have made its return motion from one stroke in time to receive the next impulse from the train of waves and thus carry out its subsequent stroke. As mentioned previously, the stroke of the hammer is half the amplitude of the wave, this design being due to the fact that the kinetic energy of the hammer is a maximum when its velocity is a maximum, this occurring in its mean position (or half stroke) considered with reference to the motion of the particles of the transmission column, The rotation of the drill steel is an important part of the design of this drill and is accomplished by means of an independent wave motor of the displacement type, which is housed transversely over the chuck. (Fig. 10 lower diagram.) The foremost of the two transverse cylinders houses a double ended plunger enlarged in the centre to a barrel which is slotted transversely. The ends of this plunger work in special packings secured between seat rings and mean pressure leak bushes. A channel formed along the side of the drill communicates with the wave inlet (in the inlet piece) and through the slotted bush, to the left hand end of the rotation plunger, the other end of which communicates with a water filled capacity formed by the rear cylinder. (16 Fig. 10.) On the arrival of a high pressure wave, this plunger moves from left to right, compressing the water in the rotation capacity, and thus storing energy which is utilised in causing a return stroke one-half cycle later. The left to right motion of this plunger must obviously synchronise with the striking motion of the hammer. Pawls are set round the chuck body and surrounded by a ratchet ring (10 Fig. 10.) The ratchet ring has a lug formed upon it which is engaged in the slot cut in the rotation plunger. The set of the teeth is such that on the left to right motion of the rotation plunger, the ratchet ring passes over the pawls, depressing them against their springs. On the return motion, the ratchet ring engages with the pawls, and the chuck body (and with it the drill steel), is rotated. It follows that this rotation of the drill steel must always occur during the return stroke of the hammer, the design being such that it cannot occur synchronously with the striking motion in any circumstances under which the drill will operate. The motion of the plunger is limited by suitable stops (15 Fig. 10), while the packings are protected as in the case of the hammer by mean pressure leak bushes.

The water flush is carried out by means of a water tube (12 Fig. 10), to whose rear end water at mean pressure is admitted from the main water column by a passage cut in the inlet piece. The amount of water passing is regulated by a needle control valve at the extreme rear of the drill (14 Fig. 10). The water tube passes through the centrally drilled hammer member and projects some 4 in. into the drill steel. The water flush in this drill is arranged for without the use of any auxiliary tanks or hose, while at the same time, it is constantly delivered at such a pressure (750 lb. per sq. in.), that dust is eliminated while the volume may be regulated so that whatever the texture of the rock, the débris may be readily removed as a sludge. In addition, the flush prevents the unnecessary pulverising of the material chipped from the rock, this fact being amply demonstrated by screen analyses of the dry sludge from various types of rock drill designed for similar duties. The continuity of the striking and rotational efforts, even though the stroke be reduced by a heavy feed, makes the drill speedy in the collaring of holes and gives great freedom from fitchering or binding. Many hundreds of feet have been drilled by wave transmission equipment in the North of England, in ground disturbed and crossed by joint planes and fissures, and the freedom from trouble in this direction was largely responsible for the marked success of the system in this case. From the design of the machine, it is seen that there is every hope of small first cost and maintenance charges since the design does not contain complex or delicate parts and the efficiency is not dependent upon the fineness of fit. In fact, a leak is in most cases essential for the efficient working of the machine.

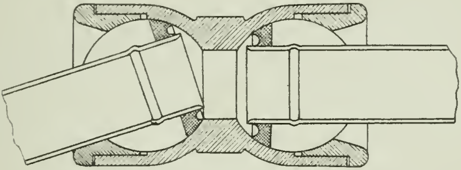


FIG. 11.

This drill has been used for holes from 4 in. diameter to 1 in. diameter in granite as well as in soft rocks, though chiefly in granite and millstone grit. The rates of penetration vary from 2 in. per min. in the first case to 18 in. a min. in the case of a 1 in. diameter hole (in Carn Brea granite). It is hoped to provide at a later date, tabulated numerical results of tests carried out on these machines.

Discussion.

Mr. F. C. Evennett said :—

Of the many subjects before engineers to-day there are few more interesting than that relating to wave phenomena through various media. Perhaps this kind of transmission was more widely known in the form of the Constantinesco Control Gear, which was extensively used on aircraft during the war. By this means it was possible to overcome the difficulty of firing bullets from a Vickers machine gun through the area swept by an airscrew without any danger of hitting the blades of the propeller. This was achieved by operating the gun lock from a generator driven by the aero engine, and so timed that the gun would fire just when the blade had passed the muzzle. It was safe to say that the greater part of the fighting aeroplanes during the latter part of the war were fitted with this mechanism. In the case under discussion the rock drill, the wave medium is water, and he would be pleased if the author would say what effect the temperature, by altering the density and elasticity, would have upon the wave length, and whether it would affect the efficiency of the machine. Also it seemed there might be some danger of freezing and bursting on closing down in very cold weather. Water at a pressure varying between 100 lb. and 1,600 lb. per sq. in. would have a slightly lower freezing-point than water at atmospheric pressure. One could imagine it remaining liquid while working, but freezing and bursting the pipes or mechanism when the pressure was reduced. The wave agitation would also help to maintain fluidity, whilst working under conditions which would quickly freeze the undisturbed liquid.

The drawing of " Flextel " (Fig. No. 11) (which might be clearer if the ball end of the pipe had been section-lined) suggests that parasitic waves might be set up by the interposing surfaces. Whether this might interfere with efficiency it would be hard to say, but it was interesting to note the analogy between such waves and the parasitic waves which, on the backs of their carrier waves, constitute the speech waves of wireless telephony. From this it seemed possible that had wave power transmission preceded wireless telegraphy by about 50 years, our modern broadcasting stations would have been situated at the water works, and our receivers would have been attached to the nearest water tap !

Dr. H. Moss, D.Sc., said there was no doubt that there was a useful future for the wave transmission system for such tools as rock drills, for which it was more convenient and efficient than the compressed air system. The claim advanced by the manufacturers that the liquid in the wave transmission system does not act as a flexible connecting rod was apt to be misleading. Mr. G.

Constantinesco in his book stated that the action in solid, liquid and gases was the same, and this view was correct. The greater elasticity of a solid resulted in a higher velocity of sound and a greater wave length, while the links used were usually small in length. Hence in a solid only a fraction of a wave length was used, whereas with a liquid a half or whole wave length might be obtained. If a solid rod of sufficient length were used, nodes and loops, as shown in Fig. 2, would also be obtained in it. A liquid connecting rod did not move as a whole, and neither did a solid rod. The elasticity of the material passes the impulse from one cross section to the next, and finite time was required in both cases. Liquid and solid transmission were the same in principle, and the complications of the wave transmission in liquids arose from the desire for flexibility. To obtain flexibility a liquid must be used and liquids had a smaller elasticity (or are more compressible), which was not wholly an advantage. The wave length (or half wave length), being of the same order as the lengths used, we obtained nodes and loops, and it was necessary for the power to be taken from certain points only of the system. The greater the compressibility also the greater the amplitude of vibration required for a given power and the greater the waste in friction. On the other hand, the greater compressibility of the liquid reduced the pressures which arose, and in a comparison of two liquids that of less elasticity was preferable to reduce the pressures on the containing tube, though the waste of energy was greater. But in a solid, which did not require a containing tube, the high elasticity was no disadvantage. The features common to all transmission, which were accentuated by the use of liquids, were thus not advantages. The advantage lay solely in the flexibility obtained and the simplicity of transmission over longer distances.

The explanation of the statement by the author that the presence of joints and bends in the pipe line did not materially affect the efficiency, lay in the fact that the principal losses of power occurred in the hydraulic generator and the drill, and those in the pipe line were comparatively small. The losses in the pipe line might be doubled by bends or increase of length without materially altering the total losses. The suggestion that only the central layers of water had large velocities (and amplitudes of vibration) applied, of course, to all motion of liquid in pipes, and it could easily be shown that the loss by friction in the pipes alone, small though it was, was larger than in ordinary hydraulic transmission of the same power at the same mean pressure.

Mr. A. Honeysett remarked that there were some points of interest not referred to in the paper, and pointed out that what was described as a means of transmitting power appeared really to be a means of transmitting impulse, the power transmitted being only that necessary to produce the impulse. With a machine working at a fixed speed and having a piston of fixed diameter and stroke there did not appear to be much provision for varying the power transmitted, and he asked whether the method could be applied to the actuation of a motor having a variable demand for power.

Another point requiring explanation was the question of frictional losses, if any, produced by the formation of the waves; in each wave length there were points of maximum and minimum pressure, the condition at each such point being in a state of rapid alternation. This meant that the density of the medium was being increased at one point and diminished at another, and although there might be no motion of the medium as a whole, yet there must be a transference of some portion of its mass between the two points. It would be interesting to know whether this transference of mass, which was probably of a molecular nature, was productive of any frictional loss of energy.

It appears that the points at which energy could be abstracted from the system must be very closely those fixed by the wave length employed, which was given as 120 ft. This would appear to introduce difficulties when the working face was not stationary, as in the case of tunnel driving. On passing a certain point it would be necessary to introduce 120 ft. of additional piping, which must, for the time being, be coiled up so as to be out of the way. It would be interesting to know whether the bends so introduced were found to increase the above-mentioned friction, assuming that such friction really existed.

Author's Reply.

In reply to Mr. Evennett :—

The well-merited prominence of the C.C. Interrupter Gear was, the writer thought, partly accounted for by the fact that the gear was the only means of achieving the desired result which was in all ways reliable and effective. For suitably synchronising machine gun fire it stood alone, as far as the writer's experience went. As a point of interest it might be mentioned that the firing-pin struck the cap before the propeller blade reached a position opposite the muzzle, on account of the ratio between the peripheral velocity of the blade and that of the bullet.

With regard to alterations in density and elasticity due to temperature differences, it might be taken that the effects were too small to have an appreciable effect in practice.

With regard to freezing, it was found that the transmission of the wave made freezing in any ordinary conditions impossible. In the case of exposed pipelines, when the generator was shut down (and low temperatures were experienced), the alternatives were: To empty the pipelines and recharge for the following shift, to lag or bury the line, as in the case of water mains, to adopt a non-freezing medium by the use of suitable solutions or a medium such as oil (as in the case of C.C. Gear), or in cases where intervals were small, leave the generator running light. In the latter case the stationary wave made freezing ordinarily impossible.

Tests indicate that the possible effects of the several surfaces of the Flexstel joint which came into contact with the column were without great effect on the efficiency of transmission. (This was observed from efficiency tests, using various pipings and Flexstel coiled and uncoiled, etc.)

The author was unable to say whether or not parasitic waves existed from this cause. Their measurement or detection would at the present stage be a matter of difficulty.

In reply to Dr. Moss :—

A statement at p. 267, lines 28-31, would indicate that the author's view was wholly in agreement with Dr. Moss' statement that wave transmission phenomena were equally associated with solids and gases, in fact, the system was equally associated with all ponderable elastic media. Since this was generally true for all columns or rods of elastic material, there was room for a misunderstanding, since the expression might be taken to indicate a denial that wave transmission effects were present in any transmission of forces through such rods of elastic material. This was not the intention of Dr. Moss, whose intention appeared to be to point out that the wave effects inherent to the material used were in many cases incidental and were ignored in the usual conception of the operation of such means of transimssion, while in wave transmission the inertia and the elasticity of the medium were the properties utilised. This did not suggest that the elasticity of materials used in other ways had no effect, but rather that a phenomenon universally met with was definitely utilised, and that therein the system was a new departure in engineering practice. By suitable adjustments power may be taken from any point in the transmission column. Though numerical data on the subject was lacking at present it appeared reasonable to suppose that the diminished amplitude near the periphery of the pipe in the case of alternating flow would play a greater part than the corresponding effect in the case of uniform flow in one direction.

In reply to Mr. Honeysett :—

It should have been made clear that at any state of the water column the condition depended upon two sets of waves, one a stationary wave whose amplitude was proportional to the excess of the supply over the power utilised, and the other a wave whose magnitude represented the power absorbed by the tool. In the case of the stationary wave, the net power absorbed approached zero, thus the power transmitted in given circumstances depended upon the ratio between these two series of waves, a ratio which was automatically adjusted to the demand, while the latter lay between no load and full load as defined by the generator. The operation of a motor having a variable power demand was thus automatically carried out in a way similar to that to be noted in connection with alternating current electrical transmission where the power factor might vary between zero and unity.

With regard to the motion of the medium which was the result of the vibration of its constituent particles, such motion must inevitably be productive of a frictional loss, though of a very small order, as seen from the results of tests under conditions where these frictional losses must be very varied, *i.e.*, though it might be assumed that the frictional losses in a given test were multiplied, it was noted that the overall efficiency was not appreciably reduced. (The existence of this loss of energy was indicated at p. 271, line 6.)

With regard to the last paragraph, the use of a portable generator would not give rise to the inconvenience mentioned, though it was understood that this did not answer the question raised. As indicated in the paper, where the simplest possible case was considered, the points at which energy could be taken from the column depended upon the half wave length adopted, in the case mentioned 60 ft. Actually, by the inclusion of a suitable condenser, power may be taken from any point in the pipe line. In the case of coiled piping, the friction losses would undoubtedly be increased, but the net effect was sufficiently small to be negligible when the addition due to the coiling was considered.

ANNUAL GENERAL MEETING.

The Thirteenth Annual General Meeting of the Society was held in the offices of the Society, 17, Victoria Street, S.W. 1, on Monday, December 11, 1922, at 6 p.m., the President, Mr. T. J. Gueritte, being in the Chair.

The notice convening the meeting was read.

The Secretary read the Report of the Scrutineers on the result of the Postal Ballot for the election of the Council and officers for the year 1923. (See page 293.)

The Report of the Council for the year 1922 was read and adopted.

Messrs. Begbie, Robinson, Cox & Knight, Chartered Accountants. were re-elected as the auditors of the Society for the ensuing year.

A vote of thanks was accorded to the Scrutineers, Messrs. E. S. C. Betteley and R. T. Quinn, for their services.

Finally, a vote of thanks having been accorded to Mr. Gueritte for taking the Chair and for his year of office, the meeting closed at 6.25 p.m.

REPORT OF THE COUNCIL FOR THE YEAR 1922.

In presenting their Thirteenth Annual Report of the Incorporated Society, the Council have to state that the membership at this date is as follows :—

Hon. Fellows	21
Fellows	43
Members	292
Associate Members	210
Associates	72
Total	638

and that 34 Corporate Members and Associates were elected during the year 1922.

The following are the associated Societies :—

Battersea Polytechnic Engineering Society.
Birmingham Association of Mechanical Engineers.
Birmingham University Engineering Society.
Crystal Palace Engineering Society.
Derby Society of Engineers.
Gloucestershire Engineering Society.
The Polytechnic (Regent Street) Engineering Society.
Queen's University (Belfast) Engineering Society.
Stoke-on-Trent Association of Engineers.
Wolverhampton & District Engineering Society.

The combined membership of these and the Society of Engineers is about 2,350. Under Clause 6 of the Regulations for the Association of Engineering Societies, the members of these societies are entitled, on the payment of a small annual subscription to receive post free the JOURNAL of the Society of Engineers, and a number of members have already availed themselves of this arrangement.

CONFERENCE *re* PROPOSED ASSOCIATION OF BRITISH ENGINEERING SOCIETIES.

The above Conference, convened by the Society, took place on September 29, 1922, preceded by a luncheon attended by 60 engineers, under the chairmanship of Mr. T. J. Gueritte. The Conference met at 3 p.m., when the number present was about

100, the Press being well represented. Mr. Gueritte explained the reasons of the Society of Engineers for convening the meeting. Mr. W. Noble Twelvetrees explained the scheme, and proposed the following resolution which was seconded by Mr. C. H. Wordingham, and carried *nem. con.*, viz. :—

> " That the meeting considers the suggestion that there be formed an Association of British Engineering Societies sufficiently important to justify the appointment of a Committee of seven to consider the question and to submit detailed proposals to the societies concerned."

The following gentlemen were appointed members of the Committee : (1) A. S. E. Ackermann, Secretary, Society of Engineers ; (2) J. H. Blizard, President, Institution of Sanitary Engineers ; (3) E. J. Cullis, Past President, Gloucestershire Engineering Society ; (4) Miss C. Haslett, Secretary, Women's Engineering Society ; (5) W. Noble Twelvetrees, President, British Section of French Society of Civil Engineers ; (6) C. H. Wordingham, President, Junior Institution of Engineers (7) Norman Wyld, Secretary, Society of Technical Engineers.

Mr. G. O. Case, M.S.E., has kindly undertaken the duties of Hon. Secretary of the Committee.

The Committee has held four meetings, and prepared the draft of the constitution of the proposed Association. This is about to be submitted with a covering letter to the societies concerned, which are being invited to suggest amendments. On these being received it is proposed to consider them and incorporate those which are approved by the Committee. The draft thus amended is to be sent with the notice calling the meeting of representatives of the societies, at which it is hoped the first Council will be appointed.

The Council have much regret in recording the deaths of the following during the year :—

Hon. Fellow.

Sir William Matthews.

Fellows.

H. V. Champion.
J. Henderson.

Members.

F. Davis.
G. S. Hewett.
W. B. Hull.
W. F. Nuthall.
W. R. Phillips.
N. J. Sanjana.

Associate Members.

E. Beadle.
J. C. Harker.

MEETINGS.

During the year 8 ordinary meetings, 8 meetings of the Council, and 25 meetings of various Committees have been held.

The following visits to works were made by members and their friends: G.P.O. Central Power Station, Blackfriars; Post Office Tunnels, King Edward Building, Newgate Street; and G.P.O. Sorting Office, on June 27; Messrs. Silvertown Lubricants, Ltd., on July 17; South Metropolitan Gas Co., on September 11.

PAPERS AND PREMIUMS.

Mr. T. J. Gueritte, B.Sc(Paris), M.Soc.Ing.Civ. de France, F.S.E., delivered his Presidential Address on February 6th, when he dealt chiefly with engineering education in France and the progress of constructional work in ferro-concrete in the United Kingdom. The following papers were contributed during the year for discussion at meetings, or for publication in the JOURNAL:—

"Air Lift Pumps," by J. A. Coombs.

"The Testing of Small Electrical Plant," by Dr. C. V. Drysdale, O.B.E., D.Sc., F.R.S.E., M.I.E.E. (Two papers.)

"Waterproofing Concrete," by H. Singh Bonsor, A.S.E.

"Fractures in Concrete," by H. Bentham.

"Locomotives of the L. & N.W.R.," by C. F. Moore.

"The Physical Properties of Clay-Mud," by Dr. Herbert Chatley, D.Sc.(Engineering), A.M.I.C.E., M.I.C.E.I., A.Inst.P.

"The Physical Properties of Clay" (*Fourth* Paper), by A. S. E. Ackermann, B.Sc. (Engineering), A.C.G.I., M.Cons.E., A.M.I.C.E.

"Coal Tubs," by Prof. Henry Adams, M.I.C.E., F.S.E.

"The Economics of Arterial Land Drainage," by C. H. J. Clayton, M.I.C.E., M.S.E.

"The Atlantic Cruise of H.M. Airship R.34," by E. E. Turner, A.M.S.E.

"Wave Power Transmission," by W. Dinwoodie.

The thanks of the Society are tendered to all authors of papers, and Premiums have been awarded as follows:—

The President's Gold Medal to Dr. C. V. DRYSDALE.

The Bessemer Premium (value £5 5s.) to Mr. E. E. TURNER.

The Nursey Premium (value £3 3s.) to Dr. HERBERT CHATLEY.

Society's Premiums (value £3 3s. each) to Messrs. C. H. J. Clayton, W. Dinwoodie and A. S. E. Ackermann.

The Clarke Premium (value £5 5s.) to Mr. R. C. Hill, A.M.S.E., of the Gloucestershire Engineering Society, for his paper on "The Submersible Pump."

The Geen Premium (value £5 5s.) to Mr. A. G. Short, of the Birmingham Association of Mechanical Engineers for his paper on "Heating."

COUNCIL AND OFFICERS FOR 1923.

The result of the Postal Ballot for the election of Council and Hon. Officers for the year 1923 was as follows :—

As President : A. MARSHALL ARTER.

As Vice-Presidents : G. A. BECKS, A. S. BUCKLE, G. NOBLE FELL.

As Members of Council : W. J. HADFIELD, F. PURTON, C. CONNOR, D. C. FIDLER, R. TWELVETREES, G. O. CASE, J. S. E. DE VESIAN, H. C. ADAMS, E. F. SPURRELL.

As Members of Council from the Class of Associate Members : J. F. J. REYNOLDS and W. HOLTTUM.

As Hon. Secretary and Hon. Treasurer : C. T. WALROND.

The thanks of the Society are due to Messrs. E. S. C. Betteley and R. T. Quinn as Scrutineers of the Ballot Lists.

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NOTE.—A complete index to the Transactions of the old Society of Engineers will be found in the last volume (1909) published by that Society, and the volumes of Transactions of the Civil and Mechanical Engineers' Society are also indexed.